USE OF WATERHYACINTHS (*Eichhornia crassipes* (MART.) SOLMS) AS A SOIL AMENDMENT AND SOURCE OF PLANT NUTRIENTS

By

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TO MY MOTHER, WIFE, CHILDREN, AND ALL MY FAMILY

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Abstract of Dissertation Presented to the Graduate Council of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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Lake Alice (U. F. Campus) waterhyacinths were used as a soil amendment and source of plant nutrients in greenhouse and field experiments. Arredondo fine sand, Lakeland fine sand, and Leon fine sand soils (5-kg portions, air dried) were mixed with dried (70 C) waterhyacinths at rates of 0, 2,231, 4,462, and 8,924 ppm and fertilizer levels of 0-0-0, 45-25-50, and 80-50-100 ppm N-P-K. Pearl millet (Pennisetum americanum (L.) K. Shum, CV. Pearlex 21) was grown as indicator crop under greenhouse conditions (25± 5 C). Yields and nutrient uptake were followed for four harvests. Plant tops were harvested six weeks after planting. Moisture was replenished weekly to 18% by weight. Optimum levels of waterhyacinths for maximum yield were above 4,000 ppm in Arredondo fine sand. For Lakeland fine sand and Leon fine sand optimum levels varied between 6,000 to 8,000 ppm. Nutrient uptake by pearl millet was enhanced by waterhyacinth applications in all soils studied. Residual effects of incorporated waterhyacinths resulted in higher C, N, K, Ca,

Mg, and Mn content of Arredondo fine sand. Carbon, N, P, K, Ca, Mg, Zn, and Mn content of Lakeland and Leon fine sand was also increased. Exchangeable Al was reduced in these two soils. Soil pH_{KCl}, ECEC, and CEC were increased in all soils studied.

In the field, waterhyacinth rates of 0, 15,000, and 30,000 kg/ha (dry matter) were incorporated in Wachula fine sand, at the Beef Research Unit, 12 miles northeast of Gainesville, Florida. Pearl millet (Pearlex 24) was grown as indicator crop. Basal fertilizer rates were 0-0-0, 30-13-25, and 60-26-50 kg/ha N-P-K. After the first harvest, 80 kg/ha N were applied to all treatments. Two harvests were collected and analyzed for nutrient uptake. Pearl millet yields were higher on all waterhyacinth treatments than on fertilizer treatments. In the second harvest basal fertilizer depressed yields and nutrient uptake on plots amended with waterhyacinths. The optimum level for maximum yield was 27,000 kg/ha waterhyacinths. Carbon, N, P, K, Ca, Mg, Zn, Mn, and Cl content of Wachula fine sand was increased by additon of waterhyacinths. Soil pH was not affected, as the soil was limed prior to waterhyacinth incorporation. Effective cation exchange capacity was increased by waterhyacinth amendment to Wachula fine sand.

INTRODUCTION

Waterhyacinth (Eichhornia crassipes (Mart.) Solms) is one of the most obnoxious aquatic weeds in the Southeastern United States. Its rapid rate of growth reflects both favorable environmental conditions and eutrophication of surface waters. Chemical and mechanical control methods have been used in an attempt to maintain streams, lakes, and waterways free of waterhyacinth growth. Biological methods of control are being investigated at the present.

In an effort to offset the high cost of waterhyacinth control possible economical uses of the weed have been investigated (5, 12, 22, 45, 49, 63, 80).

Waterhyacinths contain adequate concentrations of plant nutrients and would be very desirable green manures (22, 45, 47). The high cost of removal and dehydration offset the desirability as a soil amendment if the whole economic burden is placed on the grower. The benefits to be derived from removal of waterhyacinths from waterways and recreational aquatic areas should be taken into account to make waterhyacinth use as a soil amendment an attractive economic proposition. Removal from the aquatic environment will contribute to improvement of water quality (56, 68, 70, 73, 90) by reducing plant nutrients. Removal from the shore line will improve the aesthetics of the water body and

prevent wash down of plant nutrients into the water. If the materials are used as sources of plant nutrients in acid sandy soils they will contribute to the increased productivity of these soils.

The objectives of this study were to determine what benefits could be expected from the incorporation of waterhyacinths in the soil. The rate of nutrient release, the need for additional fertilizer, and the persistence of waterhyacinth materials in soils were also determined. Finally, optimum amounts of waterhyacinth material to be applied for maximum yields and nutrient uptake had to be established.

LITERATURE REVIEW

Waterhyacinth (Eichhornia crassipes (Mart.) Solms) is a plant of the pickerelweed family (Pontederiaceae). They are perennial or annual floating plants with creeping rootstocks and fleshy leaves which are ovate and modified for buoyancy. Flowers are cluster borne on a stalk 15-45 cm above the water. Individual blossoms are 2.5 cm wide, lavender, six lobed, with the upper lobe yellow in the center. Seeds are produced, which are viable, under favorable conditions. Plants propagate vegetatively by sending out stolons. The plant is thought to have originated in the South American tropics (48, 57, 95). Although, at the present, it has worldwide distribution (50).

Waterhyacinth plants have a rapid growth rate under favorable conditions. Knipling et al. (47, p. 1) described the physiological characteristics of waterhyacinths as follows: "They exhibit net photosynthesis rates (7.8-16.1 $mg/dm^2/hr$) and cellular characteristics associated with photorespiring plants even though they have dry matter yields (25 mt/ha) comparable to efficient terrestrial crop producers. Their high leaf area indices (5 to 8) and the efficient geometry of dense waterhyacinth stands appear unrelated to chlorophyll (4-6 mg/g) and nutrient content of plant tissue. The optimum water temperature for waterhyacinth growth is

28 to 30 C, but growth rate is relatively high over the range of 22 to 35 C. Zero growth was observed at 40 C, and death of leaves after exposure to temperatures above 40 C. Night exposure to temperature of 10 C reduced photosynthesis on following warm days. Transpiration rates vary from 1530-2400 $mg/dm^2/hr$."

Growth of waterhyacinths seems to be unaffected by a broad range of pH values which includes the pH of most natural waters. Maximum growth occurred in the range of pH 4.0 to 8.0 (32). The minimum P concentration for maximum growth was reported to be 0.10 ppm. Above this concentration, P removal from nutrient solution diminished, although luxury consumption was observed (33).

The rapid growth of waterhyacinths in natural waters suggests both favorable climatic conditions and availability of plant nutrients. Limiting concentrations of other plant nutrients have not been established for waterhyacinths. An average content of mineral nutrients of waterhyacinths, as percent of dry weight, is: 1.5-2.0 N, 0.3-0.6 P, 3.6-4.0 K, 1.6-2.0 Ca, 0.56-0.70 Mg, 0.4-0.6 Na, and 0.2-0.4 Fe. Copper, Zn, and Mn vary around 10, 300, and 60 ppm, respectively (5, 22, 47, 63, 75).

Waterhyacinths were first introduced into the United States from the tropics at a flower show in New Orleans, Louisiana in 1884. In the same year, some propogation material was brough to Pelatka, Florida. Due to the rapid growth of waterhyacinths in the new environment, overflow plants ended up in the St. Johns River, and by 1896 the whole

river basin was infested and navigation problems were beginning to be noticed (95). The waterhyacinth problem was recognized by the Federal Government in June 1897. Congress made an appropriation to study the problem in navigable waters in the Gulf and South Atlantic States, Florida, Alabama, Mississippi, Louisiana, and Texas. The existing project, "Removing the Waterhyacinth from Navigable Waters in the State of Florida" was authorized by the River and Harbor Acts of March 3, 1899, June 13, 1902, March 3, 1905 (78). Other problems associated with excessive growth of waterhyacinths are the harboring of mosquitoes and impedance of their control (69), damage to spawning grounds for fresh-water game fish, providing favorable conditions for predators and parasites, encroachment of feed vegetation, and diminishing dissolved oxygen necessary for aquatic life (78). Related problems caused by waterhyacinths are the clogging of drainage and irrigation ditches. The cost of clearing navigable waters in the Jacksonville District was $1,861,722 to June 30, 1961. The average annual cost for the 1950 to 1960 decade was $66,100. It was estimated that the benefit/cost ratio derived from control of waterhyacinths to navigation, improved flood control, drainage and irrigation, increased crops of fish and wildlife, decreased cost of malaria prevention and water treatment will amount to 15.3 for a 50-year useful life (78).

The vast area covered by waterhyacinths (32,400 ha in Florida, 1962) has spawned ideas as to possible economical utilization of the weed in some manner to offset costs of

clean-up operations. Research programs were established to study the possibility of using waterhyacinths as cattle feed (12, 22, 81) and fish foodstuffs (49). Industrial uses for the production of paper, protein, and alcohol were reviewed by Archana (5) Horticultural uses as mulch and compost material also have been reported (45, 75). The utilization of its fast growth rate and uptake of plant nutrients from wastewater was suggested (47) and documented (21, 32, 33, 56, 68, 70, 73, 77, 90, 91). The use of waterhyacinths as a soil amendment has been proposed (5, 39, 45, 47, 88).

In greenhouse studies, beneficial effects of added waterhyacinths at rates of 2,000, 4,000, and 8,000 ppm were greater in acid sandy soils (pH 4.0) than in more neutral soils (pH 6-6.5). Preliminary analysis of the data points towards beneficial effects from the high K, Na, Ca, and Mg present in waterhyacinth tissue (83).

The beneficial effects of organic amendments upon the physical properties of soils are well established (8, 18, 38, 74, 86). Organic matter (OM) increases water holding capacity of sands, promotes the free movement of water and air in clay soils, binds loose sandy soils, and provides a good environment for microorganisms (8, 7, 37, 84). On the surface and mixed with the soil, organic amendments help in preventing soil erosion by water and wind (74) Humus decreases fertilizer leaching losses because it combines with plant nutrients and holds them in available forms Organic sources of nutrients, particularly organic N compounds and

organic chelates of heavy metals may have unique value in plant nutrition under some circumstances because of their solubility or because of their steady release of available forms of nutrient elements (2, 4, 13, 17, 84, 85). Cation exchange capacity increased by OM is very important in sandy soils (28, 28, 54, 94). Under soil conditions in Florida, OM decomposes rapidly (87), requiring the use of green manures and crop residues in the rotation if the soil OM is to be maintained (84).

MATERIALS AND METHODS

Greenhouse Experiments

Lake Alice (U. F. Campus) waterhyacinths were used as the source of plant material to be incorporated in the soil. Waterhyacinths were air dried, oven dried at 70 C, and ground through a 2 mm screen in a hammer mill.

The Ap horizon of three uncultivated Florida soils, Arredondo fine sand (Grossarenic Paleudalf), Lakeland fine sand (Typic Quartzipsamment), and Leon fine sand (Aeric Haplaquod), was used in nutrient release studies. Five kg portions of the air-dried and sieved (2mm) soil were mixed with the proper amount of fertilizer and ground waterhyacinths. The experimental design was a factorial with three levels of fertilizer (F=N-P-K, ppm, 1=0-0-0; 2=45-25-50, 3=90-50-100), and four levels of dried waterhyacinths (WH, ppm, 1=0; 2=2,231, 3=4,462; 4=8,924) in completely randomized blocks of three replications. Reagent grade NH_4NO_3, KH_2PO_4, and KCl were used as mineral sources of plant nutrients. Each treatment was placed in 4 liter polyvinl containers, and seeded with pearl millet (Pennisetum americanum (L.) K. Shum, CV. Pearlex 21), thinned to ten seedlings per pot, and harvested at 6 weeks. The first harvest was made on December 5, 1972. After each harvest, the pots were reseeded and harvested at the same age. The

single exception to this was with Leon soil after the second harvest, the plants were allowed to sprout after cutting, and the pots were not replanted. The pots were seeded for harvest 4. The greenhouse temperature was maintained at 25± 5 C and soil moisture was replenished weekly by addition of distilled water to 18% moisture content by weight.

Field Experiment

The field experiment was established at the Beef Research Unit which is located 12 miles northeast of Gainesville, Florida. The soil is a Spodosol classified as Wachula fine sand (Ultic Haplaquod). The experimental area (480 m^2) was sampled to a depth of 15 cm for physical and chemical analyses. On March 19, 1974 the area was limed with 138 kg, each of dolomitic and calcitic limestone. After disking, plots 2 x 5 m were marked. During the period of April 31 to May 31, 1974 waterhyacinths were allowed to dehydrate and decompose partially before they were plowed under on June 4. The experimental design was a factorial with three rates of basal fertilizer application (1=0-0-0, 2=30-13-25, and 3=60-26-50 kg/ha of N-P-K), and three rates of waterhyacinths (1=0, 2=15,000, and 3=30,000 kg/ha, dry weight). The treatments were imposed on a completely randomized block design with four replications. Fertilizer used was from commercially available sources, formulated with micronutrients (1% FTE 503). Pearl millet (Pearlex 24) was broadcasted on June 4, 1974, and harvested six weeks later on July 19. After the first harvest, composite soil

samples were collected from each plot and prepared for chemical analysis, and 80 kg/ha of N as NH_4NO_3 were broadcasted to all treatments. The second and last harvest was done on September 4, 1974.

Chemical and Physical Analyses

Soil Samples

All soil samples were air-dried and sieved through a 2 mm screen prior to analysis. Carbon was determined by the Walkley Black wet oxidation procedure (3). Total nitrogen was done by the salycilic acid modification of the Kjeldahl method (14). Phosphorus, K, Ca, Mg, Cu, Mn, Fe, and Zn were extracted with Mehlich's extractant (55, 62). Phosphorus was analyzed colorimetrically by the phosphomolybdate method (42). Potassium determinations were made by flame spectrophotometry and the other metals by atomic absorption spectrophotometry (41). Soil pH, NO_3, NH_4, and Cl were determined with specific ion electrodes as described by Fiskell et al. (25), and Zelezny and Fiskell (96). Effective cation exchange capacity (ECEC) was determined with 1 N $CaCl_2$ as the saturating solution (20, 24, 28) and 1 N NH_4Cl as the displacing solution. For cation exchange capacity determinations, 1 N CaOAc pH 7.0 was used as the saturating solution (24). Corrections for salt trapping in cation exchange determinations were made according to Rich (66). Particle size distribution was determined according to Sanyouces (11).

Plant Samples

Oven dried (70 C) plant material was used for all chemical analyses. Plants were ground through a stainless steel Wiley Mill to pass a 20 um screen prior to ashing. For ash determination, 0 25 to 2.0 g of sample were ignited at 500 C for 8 hours, cooled and dissolved in 0.1 N HCl. Phosphorus, K, Ca, Mg, Cu, Zn, Mn, and Fe were determined by the same procedures used in soil analysis. Boron was determined in waterhyacinths only by the curcumin method (42) using a standard curve prepared as recommended by Wear (91) Total sulfur in waterhyacinths was determined by a turbidimetric method as reported by Volk (85). Nitrogen was determined by the same procedure used in soil samples Electrical conductance of water extracts of waterhyacinths were determined as described by Fiskell _et al._ (25). Aluminum and Pb in waterhyacinths were determined by atomic absorption spectrophotometry (41).

Statistical Analysis

All the data compiled wereanalyzed statistically with the Statistical Analysis Systems programs at the Northeast Regional Data Center of the State University Systems of Florida, University of Florida, Gainesville, Florida.

RESULTS AND DISCUSSION

Waterhyacinth Composition

Partial mineral composition of Lake Alice (U. F. Campus) waterhyacinths is given in Table 1. The amount of water soluble materials is a very important factor to consider when waterhyacinths are going to be added as soil amendments. These plant nutrients will be immediately released to equilibrate with the soil solution and the exchange complex (1, 83). Half of the total P, most of the Na and K, and half of the total Mg content were water soluble. Increasing the water:dry weight ratio to 100:1 did not result in increased solubility for Fe, Zn, and Mn. Solubility of P, K, Ca, and Mg apparently decreased, although the differences in concentration as compared with the 5:1 ratio compositon were attributed to sample heterogeneity. Chlorides were high, thus caution must be exercised when amending soils to be cropped with plants sensitive to Cl or excess salts. The electrical conductance of waterhyacinths in water indicated that crops susceptible to salt injury should not be planted immediately after heavy amendment with waterhyacinths. Like some municipal compost materials (36, 38) and feedlot waste products (52, 53, 65), Lake Alice waterhyacinths contained appreciable amounts of soluble salts. On a dry weight basis, waterhyacinths

TABLE 1

CHEMICAL CONSTITUENTS* OF LAKE ALICE WATERHYACINTHS

	Ash	C	N	P	K	Ca	Mg	Na	Cl	Cu	Zn	Fe	Mn	Al	Pb	EC
		%								ppm						mhos/cm
Total*	18.32	38.60	1.15	0.41	3.56	2.41	0.78	0.52	----	10.45		1002	366	1244	10	----
Water. Dry wt.																
5:1	----	-----	---	0.19	4.60	.24	0.54	.47	3.82	2	8	9	45	0	0	3.58
100:1	----	-----	---	0.15	3.65	0.17	0.39	----	----	5	9	10	40	0	0	----

*All analyses were based on dry weight

compare favorably in their nutrient content with other farm manures (64, 65) if the latter are considered on wet basis. Fresh waterhyacinths contain 5% dry matter, and their nutrient content on wet weight basis is considerably lower than for most farm manures (63, 64, 65).

Lake Alice waterhyacinths compared favorably with the average composition of other Florida waterhyacinths. However, the N content was slightly lower than the average (63). Total sulfur and Z content of Lake Alice waterhyacinths was 0.46% and 31 ppm on dry weight basis, respectively.

Soil Characteristics

Physico-chemical characteristics of the soils used in the greenhouse trials and the field experiment are given in Table 2. These soils are typical of the sandy soils found over most of Florida. Organic matter contents were low, and except for Arredondo fine sand they had wide C/N ratios (greater or equal to 20:1). The Arredondo fine sand contained adequate amounts of P and K, but Cu and Zn may have been deficient for normal plant growth. Lakeland fine sand, Leon fine sand, and Wachula fine sand had relatively low P, K, Ca, Mg, and micronutrient contents except perhaps for Fe and Mn. The Soil Extension Office recommends application of 50-45-50 kg/ha of N-P-K for pearl millet grown as a forage crop on most mineral soils in Florida and micronutrient additions are advised (44, 59, 60). Lakeland, Leon, and Wachula soils require dolomitic lime to reduce exchangeable Al (30, 34, 46, 96), raise the soil pH in water to 5.5-6.0

TABLE 2

PHYSICO-CHEMICAL CHARACTERISTICS OF UNCULTIVATED FLORIDA SOILS USED IN THE GREENHOUSE AND FIELD EXPERIMENTS

Physico-Chemical Property	Units	Soil Type: Arredondo Fine Sand	Lakeland Fine Sand	Leon Fine Sand	Wachula Fine Sand
Sand	%	90.2	96.4	93.2	90.8
Silt	%	3.3	2.1	5.2	6.7
Clay	%	6.5	1.5	1.6	2.5
C	ppm	6000	3850	9819	14040
N	ppm	679	223	551	718
Extr. Nutr.	ppm				
P		54	13	3	11
K		81	5	13	18
Ca		456	20	87	90
Mg		78	3	12	19
Cu		0	.2	.3	.6
Zn		.4	.6	1.0	1.2
Fe		5	13	18	19
Mn		28	5	0.2	0.4
Exch. Al	ppm	-	28	42	42
ECEC	meq/100g	3.20	0.66	2.14	2.15
$CEC_{pH\ 7}$	meq/100g	5.30	1.98	3.90	5.30
pH_{H_2O}		6.10	5.30	4.00	4.00
pH_{KCl}		5.50	4.60	3.50	3.60

for a better root environment (40,46,82,83) and supply Ca and Mg (8, 51, 61, 72).

Greenhouse Studies

Arredondo, Lakeland, and Leon soils were cropped to pearl millet in the greenhouse, with fertilizer and water-hyacinths as the only amendments.

Arredondo Fine Sand

Yield and nutrient uptake by pearl millet from Arredondo fine sand are given in Table 3. In the first harvest added waterhyacinths had a significant effect on yield, and uptake of N, P, K, Ca, Zn, Fe, and Mn. Significant interactions (95%) between fertilizer and added waterhyacinths were observed on uptakes of N, K, Zn, and Mn. The significance of response, and the nature of the interactions are discussed after reference to Table 4. Significant effects of added waterhyacinths on yield and N, P, K, Ca, Mg, Cu, Zn, Fe, and Mn uptake were observed in the second harvest. In the third crop, only K, Ca, Zn, and Fe uptake was significantly influenced by waterhyacinths. Interactions were observed for K, Mg, and Fe uptake. In the last harvest, yield and uptake of P, K, Ca, Mg, Cu, Zn, and Mn were significantly affected by waterhyacinths. Significant interactions were observed for P uptake only.

Regression coefficients for yield and nutrient uptake for the four pearl millet harvests versus waterhyacinths amended to Arredondo fine sand are given in Table 4. Regression analyses were done for each fertilizer level where

TABLE 3

YIELD AND NUTRIENT UPTAKE BY INDIVIDUAL HARVESTS OF PEARL MILLET ON ARREDONDO FINE SAND

Treatment WH**	P+	Yield*	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
		g/pot	-----	mg/pot	-------			------	ug/pot	---	
					First Harvest						
1	1	3.73	58	13	201	12	10	22	86	277	259
1	2	5.43	161	18	313	34	25	27	167	536	1371
1	3	6.60	202	23	366	37	30	40	234	580	1429
2	1	2.90	51	16	174	14	10	22	132	197	429
2	2	8.50	226	24	540	39	30	43	292	993	2880
2	3	8.53	302	27	600	49	36	47	368	1019	3118
3	1	2.70	52	15	166	13	9	27	150	204	638
3	2	7.07	213	22	470	37	28	48	386	780	2574
3	3	9.43	329	31	640	51	35	42	571	1047	3418
4	1	4.00	72	22	247	16	12	32	228	293	901
4	2	8.90	257	27	588	42	34	53	577	946	2878
4	3	8.63	297	31	605	40	29	47	612	995	2779
Overall mean++		6.36	185	23	409	32	24	37	317	656	1889
Std. dev.		1.23	30	4	74	5	4	14	56	163	432
					Second Harvest						
1	1	0.70	29	2	18	3	3	4	8	43	21
1	2	1.70	61	6	57	9	7	7	30	84	155
1	3	1.30	50	5	45	7	5	7	27	78	216
2	1	1.97	43	5	71	6	4	4	31	83	71
2	2	2.83	65	6	108	11	7	10	48	158	160
2	3	3.53	129	9	154	18	12	14	79	313	674
3	1	3.33	69	8	126	12	8	9	64	162	140
3	2	2.30	81	5	101	10	7	11	61	199	226
3	3	4.23	138	9	175	18	12	14	113	342	812
4	1	3.43	78	9	138	14	10	17	118	232	184
4	2	3.50	75	8	141	13	12	9	100	207	182
4	3	3.87	149	9	173	16	12	19	170	358	527
Overall mean++		2.73	81	7	109	11	8	10	71	188	281
Std. dev.		1.11	34	3	44	4	3	5	27	77	185

TABLE 3 - Continued

Treatment WH**	F+	Yield*	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
		g/pot	mg/pot					ug/pot			
					Third Harvest						
1	1	2.57	28	11	74	9	14	12	45	138	135
1	2	1.57	32	14	55	8	10	8	54	80	162
1	3	1.40	50	14	49	11	12	7	76	87	425
2	1	1.47	18	8	55	8	7	7	48	78	89
2	2	2.03	28	10	86	11	9	11	55	131	196
2	3	3.20	70	13	141	21	18	11	87	299	587
3	1	1.83	21	8	65	10	9	10	68	108	148
3	2	1.77	35	7	101	12	8	7	68	174	222
3	3	3.34	67	10	150	18	15	11	127	338	805
4	1	2.17	38	10	100	15	12	10	111	176	218
4	2	1.87	32	8	104	13	10	8	88	162	197
4	3	3.07	80	10	217	22	18	15	205	417	520
Overall mean++		2.18	42	10	100	13	12	10	86	184	281
Std. dev.		0.87	18	4	32	4	3	4	38	68	108
					Fourth Harvest						
1	1	1.46	15	10	40	7	10	5	27	63	86
1	2	2.20	32	18	85	10	10	10	40	74	130
1	3	1.27	50	14	47	10	10	6	37	74	335
2	1	1.43	14	9	67	8	4	8	25	55	56
2	2	1.97	18	12	79	9	8	10	37	64	96
2	3	2.17	28	18	80	10	8	8	44	78	144
3	1	1.33	12	8	55	8	4	5	26	45	65
3	2	4.13	45	14	180	18	13	14	95	200	304
3	3	3.40	33	15	143	17	10	12	85	128	280
4	1	2.43	23	14	106	12	8	11	55	75	137
4	2	3.17	30	16	130	14	8	11	84	113	215
4	3	4.47	58	17	190	22	14	13	111	170	384
Overall mean++		2.45	28	14	101	12	8	9	54	85	185
Std. dev.		0.88	12	2	41	4	3	3	18	85	85

*Each value is an average of three observations.

**Waterhyacinth level (1 = 0, 2 = 2231, 3 = 4482, and 4 = 8824 ppm).

+Fertilizer level (1 = 0, 2 = 45-25-50, and 3 = 80-50-100 ppm N-P-K).

++Each value is an average of thirty six observations.

TABLE 4

REGRESSION COEFFICIENTS FOR YIELD AND NUTRIENT UPTAKE VERSUS WATERHYACINTHS (WH) ADDED TO ARREDONDO FINE SAND

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
			First Harvest			
Yield	g/pot	3.73	-4.66×10^{-4}	6×10^{-6}	0.67	1
		6.61	1.05×10^{-3}	-9×10^{-6}	0.52	3
N	mg/pot	57.74	4.25×10^{-3}	6.60×10^{-7}	0.60	1
		178.53	9.21×10^{-3}	-----	0.60	2
		206.13	4.82×10^{-2}	-4.28×10^{-6}	0.62	3
K		202.36	-2.02×10^{-2}	2.63×10^{-6}	0.60	1
		360.17	2.50×10^{-2}	-----	0.42	2
		376.02	1.04×10^{-1}	-6.62×10^{-6}	0.71	3
Zn	ug/pot	68.76	1.54×10^{-2}	----	0.62	1
		176.77	4.53×10^{-2}	--	0.66	2
		216.67	9.60×10^{2}	-6.09×10^{6}	0.67	3

TABLE 4 - Continued

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
			First Harvest (Continued)			
Fe	ug/pot	271.76	-3.75×10^{-2}	4.49×10^{-6}	0.70	1
		610.53	1.81×10^{-1}	-1.56×10^{-5}	0.58	2
Mn		274.73	7.23×10^{-2}	----	0.89	1
		1544.12	4.74×10^{1}	-3.71×10^{-5}	0.51	2
		1508.41	7.88×10^{-1}	-7.27×10^{-5}	0.76	3
			Second Harvest			
Yield	g/pot	1.30	6.95×10^{-4}	-5×10^{8}	0.35	All
K	mg/pot	43.16	3.16×10^{-2}	-2.20×10^{-6}	0.43	All
Zn	ug/pot	24.36	1.19×10^{-2}	-----	0.59	All
Fe		72.06	5.44×10^{-2}	-3.67×10^{-6}	0.57	All

TABLE 4 - Continued

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
			Third Harvest			
K	mg/pot	72.37	-6.04×10^{-3}	1.25×10^{-6}	0.44	1
		55.29	1.56×10^{-2}	-1.14×10^{-6}	0.57	2
		75.57	1.71×10^{-2}	-----	0.62	3
Ca		9.06	-6.29×10^{-4}	1.5×10^{-7}	0.75	1
		6.75	9.16×10^{-4}	-5×10^{-6}	0.46	2
Mg		13.47	-2.74×10^{-3}	2.9×10^{-7}	0.76	1
Zn	ug/pot	45.66	-----	6.3×10^{-7}	0.94	1
		50.53	3.67×10^{-3}	-----	0.52	3
		64.39	1.52×10^{-2}	-----	0.49	2
Fe		132.09	-2.26×10^{-2}	3.13×10^{-6}	0.53	1
		67.46	2.76×10^{-2}	-2.15×10^{-6}	0.63	2
		110.33	6.04×10^{-2}	-5.22×10^{-6}	0.56	3

TABLE 4 Continued

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
			Fourth Harvest			
Yield	g/pot	1.51	-1.44×10^{-4}	3×10^{-8}	0.63	1
		1.41	3.61×10^{-4}	-----	0.73	3
P	mg/pot	9.75	-9.39×10^{-4}	1.6×10^{-7}	0.62	1
		17.56	2.07×10^{-3}	2.1×10^{-7}	0.52	2
		19.73	-1.66×10^{-3}	1.5×10^{-7}	0.41	3
Zn	ug/pot	27.83	-3.51×10^{-3}	7.3×10^{-7}	0.82	1
		31.15	1.49×10^{-2}	-9.7×10^{-7}	0.37	2
		36.27	3.67×10^{-3}	5.4×10^{-7}	0.82	3

interactions were significant at the 90% level or better. Coefficients of determination (R^2) were reported only if they were 0.36 or greater. All regressions were significant at the 95% level. Waterhyacinths applied without fertilizer had a depressing effect on yields in the first harvest. If one accepts fertilizer level 2 as the recommended agronomic fertilizer standard (60), yields obtained with waterhyacinths additions of 2,231 and 4,462 ppm were lower than yields from the standard, but not significantly different from the unamended soil. Additions of waterhyacinths above 4,462 ppm increased yields as predicted by equations in Table 4. The response was best described by a quadatic model. After a certain level of added waterhyacinths (greater than 4,500 ppm), plant nutrients in excess of microbial needs were supplied (65). Depressed effects were attributed to decreased N availability (67) as indicated by N uptake in Table 3.

Regression values for fertilizer level 2 were not significant because of higher variability in the results. Nevertheless, yields were higher for all waterhyacinths + fertilizer level 2 combinations than for fertilizer applications alone. At fertilizer level 3, added waterhyacinths increased yields. Applications of N reversed the depressed effect of added waterhyacinths at low levels and increased yields were obtained. Diminished returns per unit of applied waterhyacinths were observed when levels in excess of 5,631 ppm were applied. This effect can be attributed to other limiting factors in the greenhouse, possibly light

latensity. In the soil, increasing levels of waterhyacinths may decrease N availability and plant uptake due to higher concentrations of electrolytes (52), competing ions (K vs NH_4, Mg) (19), and reductions in nitrification (52, 53). Regression coefficients for P uptake were relatively low (R^2 less or equal to 0.20). The phosphatic nature of Arredondo fine sand seemed to provide adequate P supply, masking the effect of waterhyacinth supplied P.

Potassium uptake followed a pattern similar to N uptake. The decline in K uptake per unit of waterhyacinth added at fertilizer level 3 was probably caused by an increase in the concentration of Ca, Mg, and Na from extra waterhyacinths added. Influence of Ca, Mg, and Na ions on K uptake and accumulation by plants is well documented (19, 46, 58, 61, 71). No significant regression coefficients were found for Ca and Mg uptakes. These results corroborate the apparently adequate supply of these nutrients found in Arredondo fine sand (Table 2).

Waterhyacinths did not influence Cu uptake during the first harvest of pearl millet. Zinc uptake increased linearly with waterhyacinth additions at fertilizer levels 1 and 2. At the high rate of fertilizer, the response became quadratic, reaching a maximum at 8,100 ppm of waterhyacinths added, and declining thereafter for each additional unit of waterhyacinths.

Uptake of Fe was depressed by waterhyacinth additions from 0 to 4,200 ppm. From that point, when no fertilizer was applied, Fe uptake was increased by waterhyacinth additions.

When fertilizer was applied, no significant regression was obtained at level 2, but at the high rate of fertilizer, the uptake increased to a maximum observed at amendments of 5,800 ppm. Thereafter, uptake of Fe per unit of water-hyacinth added began to decline.

Manganese uptake was stimulated by waterhyacinth additions with a response that was linear when no fertilizer was added to the soil and quadratic when fertilizer was applied. Manganese uptake increased at all levels of water-hyacinths applied at fertilizer level 2, but at fertilizer level 3 Mn uptake reached a maximum at 5,500 ppm of water-hyacinths added. Thereafter, uptake per unit of waterhyacinth applied declined. This decline at the high fertilizer level was consistent for yield and N, K, Zn, Fe, and Mn uptake in the first harvest. The effect may have been due to an increase in microbial activity from energy supplied by increasing amounts of waterhyacinths. This statement seems to contradict the effect of waterhyacinths at fertilizer level 1. Since at fertilizer level 2 and 3, N-P-K were added in plentiful amounts, microbial populations were probably larger, and therefore the plants faced stronger competition for mineral nutrients. Also plant growth rates were faster, and therefore the demand for nutrients greater. These two factors coupled together will account for the reduction of yield and nutrient uptake per unit of waterhyacinth added after a maximum was reached.

In the second harvest, added waterhyacinths increased yields and K, Zn, and Fe uptake independent of fertilizer

level. Most of the responses were quadratic, with maxima at 7,000 to 8,000 ppm of added waterhyacinths. Zinc uptake was best described by a linear model. Waterhyacinths influenced positively the uptakes of N, P, Ca, Mg, Cu, and Mn, but their regressions were not significant.

Interpretations of results in harvest 3 becomes more difficult. By this time most of the waterhyacinths had decomposed, and only the more resistant materials (roots) remained. These portions exhibit cation exchange properties, high surface area, and other physico-chemical properties that influence nutrient availability (35). A depressing effect on K uptake was observed at fertilizer level 1. At the other fertilizer levels, quadratic and linear responses were observed. Obviously the K supply was influenced by residual effects of fertilizer applications. Similar effects were observed for Ca and Mg uptake at fertilizer level 1. At fertilizer levels 2 and 3 the responses were quadratic for Ca uptake. Different levels of waterhyacinths gave maximum Ca uptake. Response to waterhyacinths was quadratic for Zn uptake at fertilizer level 1. At other fertilizer levels, the best model was linear. On Fe uptake the response was similar to that observed in harvest 1.

In harvest 4, most of the available nutrients from fertilizer sources had been depleted, and the residual effects of waterhyacinths were observed. Yields were increased only at the high levels of waterhyacinths and waterhyacinth + fertilizer combinations. By this time plant nutrients were being released, probably from decomposition of dead micro-

organisms and plant root residues from previous harvests. Of importance was the fact that P uptake was influenced by waterhyacinth application. The first coefficient in the quadratic equation was negative at the three fertility levels indicating a decline in P uptake with increasing waterhyacinth levels. A minimum occurred at approximately 4,500 ppm waterhyacinths. This decline was attributed to microbial competition with plants for soil P. Thereafter, P uptake per unit of added waterhyacinths rose sharply. Response to waterhyacinths for Zn uptake at fertilizer level 1 followed the same pattern as that of P uptake. This trend changed at fertilizer levels 2 and 3.

Interpretation of residual nutrient availability is very complex. There are many variables that will affect release or exchange of certain mineral ions to plants (34, 46). Perhaps the best way to interpret waterhyacinth effects as sources of plant nutrients is by examining the total yield and nutrient uptake from Arredondo fine sand by the four harvests (Table 5). With the yield from fertilizer level 2 as the standard (60), waterhyacinths added at levels 3 and 4 with fertilizer level 3 gave 90% yield increases. Next with 65% yield increases were combinations of WH 4 x F 2, and WH 2 x F 3. A 45% increase was obtained at fertilizer level 2 and waterhyacinth levels 2 and 3. Waterhyacinths alone at the rate of 8,924 ppm gave a 14% increase in yield. Fertilizer at level 3 was as good as fertilizer level 2 for Arredondo fine sand. Control pots and pots amended with 2,231 and 4,462 ppm waterhyacinths

TABLE 5

TOTAL YIELD AND NUTRIENT UPTAKE BY
FOUR HARVESTS OF PEARL MILLET
ON ARREDONDO FINE SAND

Treatment WH**	Treatment F+	Yield*	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
		g/pot	------mg/pot------					------ug/pot------			
1	1	8.47	130	35	334	31	37	43	187	522	502
1	2	10.80	287	55	510	81	53	51	281	785	1818
1	3	10.57	353	81	507	85	57	81	374	830	2407
2	1	7.77	127	38	368	34	25	41	238	414	858
2	2	15.33	338	53	813	70	52	73	432	1348	3332
2	3	17.43	530	88	885	98	75	80	578	1708	4503
3	1	9.00	153	38	412	40	28	50	308	517	982
3	2	15.27	374	48	852	78	57	78	810	1352	3328
3	3	20.43	588	85	1107	104	73	78	876	1855	5115
4	1	12.03	211	58	582	58	42	71	511	777	1440
4	2	17.43	383	80	883	82	88	82	847	1429	3473
4	3	20.03	574	87	1185	100	73	85	1098	1840	4181
Overall mean++		13.72	338	54	719	88	53	87	527	1123	2848
Std. dev.		1.24	28	8	83	5	4	13	45	144	380

*Each value is an average of three observations

**Waterhyacinth level (see Table 3).

+Fertilizer level (see Table 3).

++Each value is an average of thirty six observations.

produced yields that were 80%, 74%, and 85% of the standard practice. From the nutrient uptakes recorded, N seemed to be the key element in determining yields in this experiment. Uptake of K, Zn, Fe, and Mn were enhanced by the waterhyacinth + fertilizer combinations.

Regression coefficients for total yield and nutrient uptake are given in Table 5. Interactions were highly significant for all variables. The decrease in yield associated with addition of waterhyacinths at 2,231 ppm was reflected in the negative slope of WH at fertilizer level 1. Above this point, additional waterhyacinths increased yields. This decline in yield as explained before, was due to microbial N requirements for decomposition of the organic material. As the level of waterhyacinths or the fertilizer increased, enough N was supplied to satisfy microbial and plant needs. At fertilizer levels 1 and 2, maximum yields were produced by 5,000 ppm and 5,400 ppm added waterhyacinths. Yields declined at higher levels of applied waterhyacinths and nutrient uptake reached a maximum at the same levels as maximum yields. In those equations (Table 6) where the linear term was negative, a decrease in yield and uptake was observed for low levels of applied waterhyacinths. At higher levels, increased nutrient uptake and yield were recorded. Optimum levels of waterhyacinths to be added to Arredondo fine sand were between 6,000 and 5,000 ppm when additional fertilizer was applied. When waterhyacinths was the only amendment, amounts greater than 4,000 ppm were required for increased yields.

TABLE 6

REGRESSION COEFFICIENTS FOR TOTAL YIELD AND NUTRIENT UPTAKE OF PEARL MILLET VERSUS WATERHYACINTHS (WH) ADDED TO ARREDONDO FINE SAND

Variable	Units	Intercept	WH	$(WH)^2$	R^1	Fertilizer Level
Yield	g/pot	8.32	-2.48×10^{-4}	7×10^{-8}	0.79	1
		11.53	1.48×10^{-3}	-9×10^{-8}	0.64	2
		10.71	3.45×10^{-3}	-2.7×10^{-7}	0.94	3
N	mg/pot	127.58	--	1.06×10^{-8}	0.81	1
		285.91	2.68×10^{-2}	-1.66×10^{-8}	0.80	2
		362.31	7.68×10^{-2}	-5.99×10^{-6}	0.81	3
P		35.47	-----	2.8×10^{-7}	0.82	1
K		344.74	-----	3.13×10^{-8}	0.84	1
		532.98	1.18×10^{-1}	-7.67×10^{-8}	0.80	2
		531.66	2.08×10^{-1}	-1.52×10^{-5}	0.96	3

TABLE 6 – Continued

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
Ca	mg/pot	32.21	-----	3.3×10^{-7}	0.90	1
		61.12	4.93×10^{3}	-2.9×10^{-7}	0.70	2
		66.34	1.47×10^{-2}	-1.23×10^{-6}	0.91	3
Mg		35.46	-4.62×10^{-3}	6×10^{-7}	0.70	1
		52.19	-----	1.7×10^{-7}	0.53	2
		58.90	6.15×10^{-3}	-5.2×10^{-7}	0.74	3
Cu	ug/pot	41.79	-----	3.7×10^{-7}	0.77	1
		52.34	9.58×10^{-3}	-7×10^{-7}	0.61	2
		64.86	3.46×10^{-3}	-----	0.37	3
Zn		153.37	3.88×10^{-2}	-----	0.96	1
		300.01	6.27×10^{-2}	-----	0.94	2
		356.24	1.33×10^{-1}	5.53×10^{-6}	0.97	3

TABLE 6 – Continued

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
Fe	ug/pot	506.08	-4.01×10^{-2}	7.96×10^{-6}	0.88	1
		832.33	2.10×10^{-1}	-1.63×10^{-5}	0.72	2
		883.68	3.68×10^{-1}	-2.82×10^{-5}	0.87	3
Mn		473.55	1.08×10^{-1}	-----	0.94	1
		1946.70	5.68×10^{-1}	-4.5×10^{-5}	0.69	2
		2469.61	1.05×10^{0}	-9.65×10^{-5}	0.84	3

The effects of added waterhyacinths on the residual soil content of plant nutrients are given in Tables 7 and 8. Soil C content was decreased by cropping with or without fertilization. Additions of waterhyacinth at any level increased the amount of soil C when measured 12 months after the date of application and four crops of pearl millet. Soil N decreased with cropping. Soil N levels on the average were higher on waterhyacinth treatments than on soils amended with fertilizer only. Residual soil P was not affected by waterhyacinth additions. The phosphatic nature of Arredondo fine sand was believed to be the dominant factor in soil P relations. Although leaching was kept to a minimum, the sum of K, Ca, and Mg was less than the effective cation exchange capacity (ECEC) of Arredondo fine sand. This indicated that in the absence of a displacing cation, these elements would have been held in the exchange complex had leaching been allowed to occur (46, 51, 58, 61, 72, 81, 92). Residual content of extractable Fe, Zn, and Cu was not affected by amendment with waterhyacinths and Mn content was only slightly increased. Due to the high base content of waterhyacinths, soil pH values in water and KCl were increased. Both increases in soil pH and organic C contribute to the increase in effective cation exchange capacity (28, 46, 54, 94). The effect of organic matter increase on cation exchange capacity (CEC) independent of pH, was observed at pH 7.0 for all treatments. However, the effect of added waterhyacinths on $CEC_{pH\ 7}$ was smaller than the effect on ECEC.

TABLE 7

CHEMICAL PROPERTIES OF ARREDONDO FINE SAND AFTER AMENDMENT WITH WATERHYACINTHS AND FOUR CROPS OF PEARL MILLET

Treatment WH**	F+	Carbon*	N	P	K	Ca	Mg	Fe	Mn	pH_{H_2O}	pH_{KCl}	ECEC	$CEC_{pH\ 7}$
		ppm										meq/100g	
1	1	5944	610	60	15	377	47	33	66	5.60	5.46	3.17	5.36
1	2	5419	594	65	31	350	45	26	65	5.80	5.50	2.91	5.33
1	3	5452	574	74	74	362	50	30	67	5.63	5.47	3.06	5.21
2	1	6199	642	60	72	422	61	29	73	5.93	5.60	3.55	5.45
2	2	6066	600	67	46	412	56	29	63	5.90	5.57	3.52	5.43
2	3	6021	614	75	71	410	62	27	70	5.93	5.57	3.34	5.46
3	1	6122	623	65	115	470	72	32	77	6.07	5.73	3.77	5.64
3	2	6625	610	69	101	462	73	27	70	6.03	5.73	3.77	5.76
3	3	6590	572	76	67	440	66	29	72	5.97	5.63	3.56	5.53
4	1	7277	669	65	223	533	99	30	60	6.30	5.93	4.33	6.26
4	2	7494	643	72	192	590	96	29	62	6.23	5.67	4.10	5.96

TABLE 7 - Continued

Treatment WH**	F+	Carbon*	N	P	K	Ca	Mg	Fe	Mn	pH_{H_2O}	pH_{KCl}	ECEC	$CEC_{pH\ 7}$
		ppm										meq/100g	
4	3	7881	663	77	205	587	98	27	75	8.17	5.83	4.15	5.90
Overall mean++		8425	618	88	103	451	69	29	72	5.98	5.68	3.80	5.83
Std. dev.		527	34	5	11	27	6	3	5	0.08	0.05	0.17	0.28

*Each value is an average of three observations.

**Waterhyacinth level (see Table 3)

+Fertilizer level (see Table 3)

++Each value is an average of thirty six observations.

TABLE 8

REGRESSION COEFFICIENTS FOR SOIL CHEMICAL CHARACTERISTICS VERSUS WATERHYACINTHS (WH) INCORPORATED INTO ARREDONDO FINE SAND

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
C	ppm	5579.40	2.17×10^{-1}	-----	0.69	All
N		577.96	-----	1.24×10^{-6}	0.45	3
P		65.13	7.56×10^{-4}	-----	0.34	2
K		15.93	2.31×10^{-2}	-----	0.96	1
		27.63	1.09×10^{-2}	8.5×10^{-7}	0.97	2
		74.76	-6.51×10^{-3}	2.58×10^{-6}	0.96	3
Ca		363.56	2.24×10^{-2}	-----	0.66	All
Mg		46.67	5.67×10^{-3}	-----	0.93	All
Mn		66.33	1.40×10^{-3}	-----	0.41	All

TABLE 8 - Continued

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
pH_{H_2O}	ppm	5.77	5.31×10^{-5}	-----	0.72	All
pH_{KCl}		5.48	4.51×10^{-5}	-----	0.81	All
ECEC	meq/100g	3.12	1.24×10^{-4}	-----	0.74	All
$CEC_{pH\ 7}$		5.29	8.52×10^{-5}	-----	0.41	All

Numerical relationships between applied waterhyacinths and residual soil properties are given in Table 8. Residual soil C increased linearly with waterhyacinth additions. The persistence of organic materials added was traced to the root fractions of waterhyacinths. Root fragments were visible during sample handling and analysis. Persistence of root tissue in amended soils has been well documented (17). Waterhyacinths grown in eutrophic waters have larger top root ratio than those grown in oligo or mesotrophic waters (47). Waterhyacinths with large root masses will contribute to the buildup of soil OM content. Those with smaller root systems will provide more ready available plant nutrients when incorporated into the soil. The importance and benefits of soil OM have been discussed elsewhere (8, 15, 18, 29, 34). Residual soil N was increased by the addition of waterhyacinths when applied in large amounts or in conjunction with fertilizer N. This was also true for P and K contents in the soil. However, addition of fertilizers changed the soil K response to waterhyacinths applied from linear to quadratic and at high fertilizer levels, residual soil K decreased with increasing waterhyacinth levels possibly due to increased K uptake by crops. At high levels of waterhyacinths, soil K increased regardless of fertilizer application. Calcium, Mg, and Mn increased linearly with added waterhyacinths. Most Ca in plant tissue is in the cell wall structure as Ca pectates (46) which resist decomposition by soil organisms. Soil pH increased linearly with waterhyacinth addition because of K, Ca, Mg, and Na added and the large buffer capacity of

organic materials. The effects of increased pH and OM in the soil resulted in the higher ECEC and CEC observed with increasing levels of waterhyacinths applied. Soil pH and ECEC are essential to consider where improved soil productivity and better plant nutrition are desired (83, 86).

Lakeland Fine Sand

Yields and nutrient uptake by four harvests of pearl millet grown on Lakeland fine sand are given in Table 8. In harvest 1 all variables were effected by addition of waterhyacinths. Declines in yield and nutrient uptake were observed at the higher level of waterhyacinth application. The optimum rate of addition was exceeded and further increases would not be beneficial to plant growth. Lakeland fine sand was less fertile than Arredondo fine sand (Table 2). The beneficial effect of added waterhyacinths at levels 2,231 and 4,462 ppm could be interpreted as an overall improvement in the soil fertility status. The decline at 8,824 ppm was attributed to unfavorable plant growth conditions brought about possibly by water repellency problems (43) and high salt concentrations (65). Water repellency problems in sands were studied by several investigators (8, 10), and it is not uncommon to Lakeland fine sand soil types (43). This phenomenon would affect water redistribution in soils and its availability to growing crops (43). Nutrient movement and solute problems were also effected (25). No measurements other than visual observations were made on the wetting of the pot surface.

TABLE 9

YIELD AND NUTRIENT UPTAKE BY PEARL MILLET
ON LAKELAND FINE SAND

Treatment N*	P*	Yield*	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
		g/pot	-------mg/pot-------					------ug/pot------			
					First Harvest						
1	1	1.00	23	3	17	3	4	10	49	42	74
1	2	4.40	160	16	161	6	4	16	165	580	582
1	3	5.60	233	27	300	7	4	20	229	380	605
2	1	2.47	34	6	123	7	5	15	123	106	323
2	2	6.93	201	22	426	19	19	35	547	1129	1160
2	3	7.97	273	31	502	19	19	29	530	1059	1110
3	1	2.50	39	9	136	9	6	15	141	121	343
3	2	9.13	199	24	503	22	21	41	743	1117	1311
3	3	7.57	259	30	540	22	20	38	650	1091	1160
4	1	2.07	47	7	111	6	5	17	151	129	329
4	2	7.17	177	23	450	19	19	42	622	910	1291
4	3	6.50	202	23	436	21	19	33	592	914	1056
Overall mean**		5.19	154	19	309	13	12	26	379	622	779
Std. dev.		1.05	25	4	68	3	2	7	90	200	234
					Second Harvest						
1	1	0.60	17	1	9	2	1	3	13	23	47
1	2	2.97	59	7	73	9	6	15	145	301	646
1	3	4.17	130	10	99	8	4	23	124	209	864
2	1	1.53	21	2	51	5	3	9	52	61	179
2	2	3.47	104	6	109	10	7	13	106	200	500
2	3	7.37	156	19	219	19	17	26	201	588	1071
3	1	1.60	32	5	60	4	3	13	50	74	136
3	2	3.73	64	9	130	11	8	15	123	192	422
3	3	4.07	139	10	143	11	9	13	194	322	534
4	1	1.40	42	3	63	5	4	8	73	112	107
4	2	2.93	91	6	129	10	9	15	149	234	335
4	3	5.93	161	14	242	16	14	23	294	491	791
Overall mean**		3.31	93	7	110	9	7	15	127	233	469
Std. dev.		1.51	33	4	55	4	3	6	70	132	269

TABLE 9 - Continued

Treatment WH**	F+	Yield*	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
		g/pot	------mg/pot-------					-----ug/pot------			
					Third Harvest						
1	1	0.77	13	2	5	4	2	6	67	57	164
1	2	1.20	17	3	16	5	2	11	79	102	572
1	3	1.53	43	7	37	8	2	13	118	102	866
2	1	0.83	13	2	38	4	2	7	83	87	275
2	2	1.63	18	4	52	7	4	16	146	125	637
2	3	2.50	28	10	69	11	6	15	121	208	888
3	1	1.43	19	4	59	8	3	15	124	84	285
3	2	1.87	22	5	91	8	4	15	175	151	838
3	3	3.87	67	11	187	18	8	18	272	410	998
4	1	2.07	40	4	135	10	6	19	138	187	256
4	2	2.80	56	8	163	12	7	21	255	277	599
4	3	3.10	84	10	182	14	7	22	512	326	952
Overall mean++		1.98	33	6	96	9	4	15	173	175	594
Std. dev.		0.58	18	2	32	2	1	5	78	77	210
					Fourth Harvest						
1	1	0.57	11	5	9	3	2	4	22	28	180
1	2	0.53	9	3	8	2	1	5	21	24	185
1	3	0.47	12	4	10	2	1	4	20	31	175
2	1	0.93	8	4	33	5	4	6	40	54	158
2	2	0.83	9	8	26	4	5	7	39	48	187
2	3	0.70	9	7	20	4	4	6	30	33	139
3	1	1.03	10	8	44	5	5	8	48	49	118
3	2	1.10	11	9	46	6	5	9	47	54	189
3	3	1.93	16	11	67	7	6	10	58	92	344
4	1	3.77	32	14	174	11	11	18	120	149	290
4	2	3.43	28	15	141	9	10	15	108	175	410
4	3	4.27	44	21	197	14	16	23	162	281	570
Overall mean++		1.82	18	8	65	8	8	10	60	88	245
Std. dev.		0.92	10	3	40	3	3	4	30	73	117

*Each value is an average of three observations.

**Waterhyacinth level (see Table 3).

+ Fertilizer level (see Table 3).

++Each value is an average of thirty six observations.

In the second harvest, only K, Ca, and Mg uptake were significantly affected by waterhyacinths. As Lakeland fine sand is an acid soil (with relatively low K, Ca, and Mg contents) the effect of waterhyacinth on the uptake of these ions was attributed to their increased supply in the soil. Although some problems with water repellency persisted, they were less prominent than in the first harvest, possibly as a result of advanced decomposition of waterhyacinths and increased frequency of irrigation to avoid drying of the soil. Yield and nutrient uptake followed the same pattern observed in the first harvest.

All measured variables except Mn uptake were significantly affected by waterhyacinths in the third harvest. Yields and nutrient uptake were increased by waterhyacinths. The magnitude of effects was smaller than in the first and second harvests for the intermediate levels of applied waterhyacinths. Residual fertilizer effects were not significant in the final harvest. Yields and nutrient uptakes directly reflected the effect of added waterhyacinths. In contrast to results obtained in Arredondo fine sand, micronutrient uptake was positively influenced by waterhyacinths added in three out of four harvests on Lakeland fine sand. These effects were possibly due to an increase in supply and availability brought about by waterhyacinth additions to the soil and the ensuing increase in microbial activity (2, 29, 34).

To determine a quantitative relationship between waterhyacinths applied versus yield and nutrient uptake by pearl millet, linear and curvilinear models were calculated.

The results are given in Table 10. In the first harvest suitable equations were calculated for Ca, Mg, and Zn uptake. For yield and other plant nutrients, the variability of the data accounted for low coefficients of determination (R^2). In the three cases, significant interactions between waterhyacinths and fertilizer were observed. Optimum waterhyacinths levels were at 5,000 to 7,000 ppm. The same levels gave optimum results through harvest 2. Only Mg uptake could be adequately described by a linear model when no fertilizer was applied.

In the third harvest, in addition to enhancement of K, Ca, and Mg uptake, Cu, Zn, and Fe uptake was increased by waterhyacinth applications. Fertilizer effects were not significant, and regression equations were calculated on the basis of waterhyacinths applied. All responses were positive.

Total yield and nutrient uptake of all crops of pearl millet on Lakeland fine sand are given in Table 11. With treatment 90-45-100 ppm N-P K (F 2) as the recommended agronomic practice minus lime (59, 60), waterhyacinths at levels of 2,231 and 4,462 ppm gave 104 and 117% yield increases when applied with F 2. Treatments WH 3 x F 3, WH 4 x F 2, WH 3 x F, and WH 2 x F 2 gave yield increases of 90, 79, 64, and 41% respectively. When no fertilizer was applied, applications of waterhyacinths at levels of 2,231, 4,462, and 8,924 ppm gave yields that were 64, 72, and 102% of the recommended agronomic practice. Total yields at all waterhyacinth levels were higher than those on control pots.

TABLE 10

REGRESSION COEFFICIENTS FOR YIELD AND NUTRIENT UPTAKE VERSUS WATERHYACINTHS (WH) ADDED TO LAKELAND FINE SAND

Variable	Units	Intercept	WH	(WH)^2	R^2	Fertilizer Level
			First Harvest			
Ca	mg/pot	3.30	1.85×10^{-3}	-1.8×10^{-7}	0.89	1
		6.84	5.72×10^{-3}	-4.9×10^{-7}	0.93	2
		7.59	5.49×10^{-3}	-4.5×10^{-7}	0.88	3
Mg		3.74	5.81×10^{-4}	-5×10^{-8}	0.55	1
		5.15	6.28×10^{-3}	-5.4×10^{-7}	0.82	2
		5.28	5.85×10^{-3}	-4.6×10^{-7}	0.78	3
Zn	ug/pot	52.80	3.20×10^{-2}	-2.38×10^{-8}	0.93	1
		188.48	2.09×10^{-1}	-1.77×10^{-5}	0.95	2
		235.71	1.52×10^{-1}	-1.28×10^{-5}	0.85	3

TABLE 10 - Continued

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
			Second Harvest			
Mg	mg/pot	1.66	2.88×10^{-4}	------	0.50	1
			Third Harvest			
K	mg/pot	3.06	1.45×10^{-2}	------	0.95	1
		14.17	1.63×10^{-2}	------	0.86	2
		21.58	4.64×10^{-2}	-3.12×10^{-6}	0.62	3
Ca		3.68	------	8×10^{-8}	0.88	1
		4.80	7.64×10^{-4}	------	0.83	2
		5.39	3.88×10^{-3}	-3.4×10^{-7}	0.76	3
Mg		2.01	------	5×10^{-8}	0.83	1
		2.08	5.41×10^{-4}	------	0.84	2
		1.75	2.31×10^{-3}	-1.9×10^{-7}	0.81	3
Cu	ug/pot	10.15	1.25×10^{-3}	------	0.36	All

TABLE 10 - Continued

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
			Third Harvest (Continued)			
Zn	ug/pot	62.62	9.20×10^{-3}	------	0.53	1
		69.97	1.90×10^{-2}	------	0.59	2
		125.71	------	4.97×10^{-6}	0.73	3
Fe		56.07	------	1.63×10^{-6}	0.97	1
		107.96	------	2.13×10^{-6}	0.66	2
		60.80	1.01×10^{-1}	-8.1×10^{-6}	0.55	3
			Fourth Harvest			
Yield	g/pot	0.55	------	4×10^{-8}	0.72	All
N	mg/pot	7.56	------	3.3×10^{-7}	0.56	All
P		4.05	6.66×10^{-4}	6×10^{-6}	0.71	All
K		12.70	------	1.99×10^{-6}	0.77	All

TABLE 10 - Continued

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
			Fourth Harvest (Continued)			
Ca	mg/pot	2.06	1.02×10^{-3}	------	0.64	All
Mg		1.24	1.18×10^{-3}	------	0.64	All
Cu	ug/pot	5.16	------	1.8×10^{-7}	0.67	All
Zn		25.09	------	1.32×10^{-6}	0.70	All
Fe		29.30	------	2.16×10^{-6}	0.51	All
Mn		158.62	------	3.29×10^{-6}	0.42	All

TABLE 11

TOTAL YIELD AND NUTRIENT UPTAKE BY FOUR HARVESTS OF PEARL MILLET ON LAKELAND FINE SAND

Treatment WH**	F+	Yield*	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
		g/pot	--------mg/pot-------					-----ug/pot--------			
1	1	2.93	63	11	39	11	9	23	152	150	445
1	2	9.10	243	29	259	22	13	47	410	1007	1996
1	3	11.17	419	49	445	23	12	60	491	721	2510
2	1	5.87	76	14	246	20	13	37	278	287	935
2	2	12.87	332	38	611	39	34	70	840	1502	2485
2	3	18.53	465	66	808	53	45	75	882	1888	3309
3	1	6.57	97	24	299	23	17	52	361	327	882
3	2	14.93	296	45	759	46	38	81	1087	1523	2557
3	3	17.33	481	62	947	58	43	81	1175	1904	3036
4	1	9.30	161	27	484	32	26	62	483	577	981
4	2	16.33	341	53	883	50	43	93	1136	1497	2636
4	3	19.80	472	67	1058	66	57	101	1560	2002	3270
Overall mean++		12.11	287	40	570	37	29	65	738	1115	2087
Std. dev.		1.62	24	5	61	3	3	10	89	173	414

*Each value is an average of three observations.

**Waterhyacinth level (see Table 3).

+Fertilizer level (see Table 3).

++Each value is an average of thirty six observations.

The same was true for nutrient uptake. All plant nutrients studied seemed to be limiting for pearl millet production on Lakeland fine sand.

Regression coefficients for total nutrient uptake are given in Table 12. Yield response could not be adequately described by linear or quadratic models. Both fertilizer and applied waterhyacinths had significant effects on yield. No statistically significant interaction between fertilizer and waterhyacinths was observed for yields of pearl millet. These conclusions could also be used to describe total P and Mn uptake. All other plant nutrients, except Cu, showed fertilizer x waterhyacinth interactions. Data in Table 11 indicated that waterhyacinths increased yields and nutrient uptake when applied to Lakeland fine sand. This response was in most cases quadratic, with an optimum application level at 6,000 to 8,000 ppm when no additional fertilizer was applied. Linear responses may become quadratic at higher levels of waterhyacinth application. Optimum levels in those cases could be 10,000 ppm.

The residual effects of applied waterhyacinths on chemical properties of Lakeland fine sand are given in Table 13. As was the case in Arredondo fine sand, applied waterhyacinths increased soil C and N. The C/N ratio was on the average very close to 20:1, suggesting equilibrium conditions on waterhyacinth decomposition had been reached. The high Ca content of waterhyacinths increased stability of residual OM and contributed to higher N content (27, 76). Extractable P increased with increasing rates of applied waterhyacinths.

TABLE 12

REGRESSION COEFFICIENTS FOR TOTAL NUTRIENT UPTAKE VERSUS WATERHYACINTHS (WH) ADDED TO LAKELAND FINE SAND

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
N	mg/pot	63.25	4.27×10^{-3}	7.5×10^{-7}	0.91	1
		255.84	2.10×10^{-2}	-1.33×10^{-6}	0.44	2
		418.88	2.29×10^{-2}	-1.82×10^{-6}	0.67	3
K		53.85	7.54×10^{-2}	-3.10×10^{-6}	0.95	1
		271.32	1.61×10^{-1}	-1.05×10^{-5}	0.96	2
		458.13	1.65×10^{-1}	1.10×10^{-5}	0.91	3
Ca		12.99	2.23×10^{-3}	------	0.89	1
		22.19	8.18×10^{-3}	-5.7×10^{-7}	0.83	2
		25.43	1.17×10^{-2}	-8.1×10^{-7}	0.81	3
Mg		9.09	1.85×10^{-3}	------	0.95	1
		14.25	8.73×10^{-3}	-6.3×10^{-7}	0.90	2
		15.14	1.08×10^{-2}	-7.1×10^{-7}	0.85	3

TABLE 12 - Continued

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
Cu	ug/pot	47.36	4.55×10^{-3}	------	0.40	All
Zn		177.87	3.80×10^{-2}	------	0.86	1
		412.82	2.24×10^{-1}	-1.60×10^{-5}	0.98	2
		570.02	1.17×10^{-1}	------	0.89	3
Fe		154.88	4.62×10^{-2}	------	0.93	1
		1043.69	1.99×10^{-1}	-1.87×10^{-5}	0.44	2
		817.13	4.44×10^{-1}	-3.53×10^{5}	0.83	3

TABLE 13

CHEMICAL PROPERTIES OF LAKELAND FINE SAND AFTER AMENDMENT WITH WATERHYACINTHS AND FOUR CROPS OF PEARL MILLET

Treatment WH**	Treatment P+	Carbon*	N	P	K	Ca	Mg	Fe	Mn	Zn	Al Exch	pH_{H_2O}	pH_{KCl}	ECEC	CEC pH 7
		ppm												meq/100g	
1	1	3720	200	15	2	14	1	14	5	0.4	20	5.43	4.67	0.57	1.65
1	2	3720	161	22	3	14	1	13	3	0.3	21	5.60	4.63	0.60	2.09
1	3	3733	216	26	4	12	1	12	3	0.5	22	5.67	4.57	0.64	2.01
2	1	4200	192	19	27	54	14	12	5	0.6	15	5.27	4.77	0.72	1.96
2	2	3987	244	24	34	55	11	11	4	0.5	15	5.53	4.67	0.73	2.01
2	3	3720	223	32	23	49	7	11	5	0.4	15	5.60	4.63	0.61	2.04
3	1	4226	229	20	76	111	29	11	6	0.7	6	5.40	5.00	0.96	2.23
3	2	4413	266	32	50	101	25	13	6	0.7	9	5.43	4.90	0.85	2.15
3	3	4427	242	43	50	102	24	12	6	0.7	9	5.47	4.67	0.93	2.14

TABLE 13 - Continued

Treatment WH**	F+	Carbon*	N	P	K	Ca	Mg	Fe	Mn	Zn	Al Exch	pH_{H_2O}	pH_{KCl}	ECEC	CEC_{pH7}
		ppm												meq/100g	
4	1	4640	295	29	148	205	54	11	9	1.3	4	5.73	5.47	1.48	2.35
4	2	5040	343	39	150	208	53	11	9	1.2	4	5.70	5.33	1.37	2.58
4	3	4907	316	48	124	191	48	11	8	1.0	5	5.73	5.30	1.41	2.58
Overall mean**		4228	246	29	58	93	22	12	6	0.7	12	5.54	4.90	0.92	2.17
Std. dev		271	33	3	19	10	2	2	1	0.1	2	0.10	0.05	0.08	0.21

*Each value is an average of three observations.

**Waterhyacinth level (see Table 3)

+Fertilizer level (see Table 3).

++Each value is an average of thirty six observations

Potassium, Ca, and Mg supplies in soil were increased as the result of waterhyacinth amendment. Zinc and Mn concentrations were also increased, but Fe and Cu were not. Iron oxides coat lakeland fine sand particles, thus Fe supply to soil solution and plant roots would be in equilibrium with the Fe oxides. As seen from Fe uptake (Table 12), waterhyacinths did influence availability and release of Fe from the soil. Most of the soil Cu was probably removed by cropping, and any reserve left after four harvests of pearl millet was minimal or not extractable with the solution used.

Exchangeable Al was reduced considerably by waterhyacinths. Possible mechanisms are increased chelation capacity of soil OM (26, 28, 54, 96) as a consequence of increased OM content and pH associated with waterhyacinth additions. Reduced solubility of Al at higher pH values (93, 96) would also account for the lowering of exchangeable Al after soil amendment with waterhyacinths. Aluminum displacement from the exchange complex was promoted by the high Ca, Mg, and K content of waterhyacinths. Soil pH was increased by addition of waterhyacinths. Effective cation exchange capacity and CEC of Lakeland fine sand were also increased.

Reduction in exchangeable Al and increased pH and ECEC contributed to a better root environment (34, 46). These factors added to an increased supply of N, P, K, Ca, Mg, Mn, and Zn enhanced the beneficial effects of added waterhyacinths to Lakeland fine sand. Benefits were demonstrated by higher yields and nutrient uptake.

Quantitative relationships between soil chemical properties and applied waterhyacinths are given in Table 14. Positive linear responses were observed in most cases. Waterhyacinths, as discussed earlier, had a negative effect on exchangeable Al. In most instances, the effect of added waterhyacinths was independent of fertilizer application. Close scrutiny of the numerical value of coefficients of regression where fertilizer levels were specified indicated that they were not too far apart, and the equations may have not been significantly different.

The effects of applied waterhyacinths on the fertility of Lakeland fine sand were beneficial. Response increased with increasing levels of waterhyacinths to an optimum at 7,000 to 8,000 ppm.

Leon Fine Sand

Leon fine sand had a relatively low supply of P and K (Table 2). Its low pH indicated limited microbial activity and decomposition of OM, from which a low rate of N supply can be inferred (8, 29, 34, 40). Exchangeable Al saturated about 20% of the ECEC, which along with low Ca and Mg contents delineated an unproductive soil in its natural state (30, 46). As indicated in Table 2, the micronutrient supply in this soil was rather limited or deficient for crop production. Under such conditions, response to any soil amendment within reasonable management practices would bring yield increases. This was the case when water-hyacinths were added with or without additional fertilizer.

TABLE 14

REGRESSION COEFFICIENTS FOR SOIL CHEMICAL CHARACTERISTICS VERSUS WATERHYACINTHS (WH) INCORPORATED INTO LAKELAND FINE SAND

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
C	ppm	3720.88	1.30×10^{-1}	------	0.55	All
N		192.73	1.35×10^{-2}	------	0.54	All
P		21.47	1.99×10^{-3}	------	0.43	All
K		3.16	9.74×10^{-3}	8.4×10^{-7}	0.90	All
Ca		9.84	2.14×10^{-2}	------	0.98	All
Mg		1.53	5.92×10^{-3}	------	1.00	1
		0.92	4.53×10^{-3}	1.5×10^{-7}	1.00	2
		-1.33	5.44×10^{-3}	------	0.98	3
		-0.13	5.77×10^{-3}	------	0.98	All
Zn		0.38	8.79×10^{-5}	------	0.82	All

TABLE 14 - Continued

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
Mn	ppm	5.03	------	5×10^{-8}	0.82	1
		3.13	6.29×10^{-4}	------	0.94	2
		3.40	5.81×10^{-4}	------	0.90	3
		3.69	5.56×10^{-4}	------	0.94	All
Exch. Al		21.31	-3.58×10^{-3}	1.9×10^{-7}	0.95	All
pH_{KCl}		4.56	8.71×10^{-5}	------	0.92	All
ECEC	meq/100g	0.56	9.25×10^{-5}	------	0.93	All
$CEC_{pH\ 7}$		1.93	6.14×10^{-5}	------	0.49	All

Yields and nutrient uptake by four crops of pearl millet on Leon fine sand are given in Table 15. In the first harvest, all plant measurements showed a highly significant response to both fertilizer and waterhyacinth additions. This indicated that for the first crop, primary plant nutrients N-P-K were supplied in adequate amounts by fertilizers or waterhyacinths independently. Absorption of other plant nutrients was also enhanced by both amendments.

In the second crop, the residual effect of fertilizers and waterhyacinths significantly increased yields and nutrient uptake. As expected, yields and nutrient uptake were of lower magnitude for most treatments, except in a few cases where high levels of both waterhyacinths and fertilizer were applied. Interactions in N uptake were observed in this second crop.

The third harvest was from the re-growth of pearl millet planted for the second crop and relatively low yields were obtained. Waterhyacinths at all levels were better or equal to the highest fertilizer applications in producing pearl millet herbage. Plant contents of Ca and Mg were increased by additions of waterhyacinths. A significant interaction was observed on P uptake between applications of waterhyacinths and fertilizer.

For the fourth and final crop, the pots were "cultivated" and reseeded. The effect of the nutrient reserves in the seed was evident on yields and nutrient uptake by pearl millet on this last harvest. All quantities of nutrients taken up were substantially higher than in the third harvest.

TABLE 15

YIELD AND NUTRIENT UPTAKE BY PEARL MILLET ON LEON FINE SAND

Treatment WH**	F+	Yield*	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
		g/pot	----	----	mg/pot	------	----	ug/pot	----	----	
					First Harvest						
1	1	0.30	12	0.4	6	0.4	0.3	2	7	20	4
1	2	3.20	139	16.7	138	4.6	4.1	26	151	260	123
1	3	3.40	138	18.4	187	4.3	3.3	26	170	265	82
2	1	3.03	78	10.3	167	4.4	3.5	21	123	193	344
2	2	3.53	123	17.6	200	5.9	5.3	23	182	295	301
2	3	5.17	192	30.3	312	9.4	7.3	32	290	440	469
3	1	5.13	140	18.8	277	9.7	7.3	29	255	361	659
3	2	5.23	158	31.8	318	11.6	10.6	36	405	453	554
3	3	5.33	205	33.5	329	10.3	9.0	39	349	420	588
4	1	4.50	125	23.7	304	10.3	8.0	36	297	363	693
4	2	5.43	164	36.6	342	11.2	10.6	37	492	471	705
4	3	6.37	212	41.4	414	13.2	11.0	64	532	566	846
Overall mean++		4.22	140	23.3	250	7.9	6.7	31	271	342	447
Std. dev		1.27	39	9.5	71	2.6	2.1	10	83	89	150
					Second Harvest						
1	1	0.20	9	0.4	2	0.1	0.1	1	2	9	1
1	2	1.03	38	6.7	27	0.6	0.5	6	20	54	21
1	3	2.13	91	12.4	55	1.7	1.3	8	51	102	39
2	1	2.17	53	4.4	71	2.9	2.7	11	65	122	192
2	2	1.97	69	11.1	83	2.5	2.2	15	64	124	136
2	3	4.90	182	33.8	207	6.5	6.0	26	165	361	326
3	1	3.07	68	9.0	101	4.9	3.9	13	82	146	326
3	2	3.53	125	16.5	148	5.6	4.6	11	135	206	306
3	3	5.03	182	30.6	231	8.2	7.2	34	255	299	451
4	1	2.90	84	13.7	117	6.0	4.2	17	120	171	337
4	2	4.60	146	19.7	186	7.1	6.3	18	183	236	387
4	3	5.70	200	27.4	242	10.0	8.4	36	302	437	469
Overall mean++		3.10	104	15.4	123	4.7	4.0	16	120	189	249
Std. dev		0.85	20	5.6	35	1.4	1.2	9	43	75	94

TABLE 15 - Continued

Treatment WH**	F+	Yield*	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
		g/pot	--------mg/pot--------					----ug/pot----			
					Third Harvest						
1	1	0.33	12	1.2	5	0.3	0.4	2	18	21	8
1	2	0.77	24	9.2	27	0.6	0.7	5	48	52	18
1	3	1.87	89	28.4	78	1.8	2.4	18	118	117	39
2	1	1.77	28	5.4	70	3.0	4.1	11	91	112	320
2	2	1.53	44	15.8	84	2.3	2.7	10	88	103	152
2	3	2.83	84	34.4	123	4.3	5.6	19	131	187	245
3	1	2.03	27	11.3	85	4.9	5.3	12	123	102	542
3	2	2.70	84	22.3	155	5.5	5.7	19	165	194	358
3	3	2.77	82	27.8	149	5.1	5.9	22	184	201	327
4	1	2.23	44	18.2	132	8.3	8.8	14	172	165	481
4	2	2.27	50	20.8	148	8.4	7.4	12	178	198	427
4	3	2.33	80	20.9	183	7.0	8.8	19	238	202	297
Overall mean++		1.95	51	17.9	101	4.0	4.8	14	127	138	288
Std. dev.		0.56	13	8.5	29	1.3	1.4	4	37	49	126
					Fourth Harvest						
1	1	0.80	37	1.5	14	1.1	1.5	8	34	69	19
1	2	2.57	83	18.8	38	5.2	4.3	14	94	175	110
1	3	1.00	44	9.9	41	0.7	0.4	8	25	74	18
2	1	1.83	28	5.2	48	3.3	4.1	6	50	77	222
2	2	4.03	92	32.7	156	7.8	10.8	24	114	244	398
2	3	4.40	90	51.1	124	7.9	10.9	20	118	229	447
3	1	1.77	29	8.1	97	4.9	2.7	9	54	87	321
3	2	3.93	87	28.1	200	8.8	8.2	17	114	199	507
3	3	8.40	110	58.9	301	12.2	11.6	38	185	315	738
4	1	3.33	42	23.4	200	8.3	4.5	17	124	191	712
4	2	5.70	83	41.2	380	14.4	9.7	17	284	321	881
4	3	8.77	140	80.2	512	18.1	13.5	43	337	415	1005
Overall mean++		3.53	89	28.1	178	7.7	6.7	18	128	200	448
Std dev.		0.93	23	7.2	86	2.5	2.8	9	85	77	112

*Each value is an average of three observations.

**Waterhyacinth level (see Table 3).

+Fertilizer level (see Table 3).

++Each value is an average of thirty six observations.

Significant interactions were observed for all measurements recorded except for Zn, Fe, and Mg uptake. The effects of waterhyacinths and fertilizer were significant on yield and nutrient uptake.

Predictive models on the response of pearl millet to waterhyacinth incorporation into Leon fine sand are given in Table 16. Optimum levels of applied waterhyacinths varied between 7,000 ppm for yield to 10,000 ppm for P uptake in the first harvest. For uptake of K, Ca, Mg, Fe, and Mn the optimum level was 8,000 ppm. In the second harvest, interactions between fertilizer and waterhyacinths were observed for N uptake. Optimum level of waterhyacinth were 8,000 ppm when no fertilizer was applied, 9,000 ppm when 45-25-50 ppm of N-P-K were applied, and 7,000 ppm at the highest level of fertilizer. For all other nutrients, the optimum remained the same. Quadratic models adequately described yield, K, Ca, Mg, Fe, and Mn uptake for the third harvest. Optimum level based on these equations remained about 10,000 ppm Linear models were better than quadratic in describing P uptake when no fertilizer was applied and Zn uptake at all fertilizer levels. To this stage, waterhyacinths had effects on yields and nutrient uptake of pearl millet independent of fertilizer applications. Plant nutrients were adequately supplied to roots and soil microorganisms (79) by decomposition of waterhyacinth tissues.

In the last harvest, all variables studied showed interaction effects between waterhyacinths and fertilizer. All regressions were highly significant. Iron uptake had an

TABLE 18

REGRESSION COEFFICIENTS FOR YIELD AND NUTRIENT UPTAKE VERSUS WATERHYACINTHS (WH) ADDED TO LEON FINE SAND

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertility Level
			First Harvest			
Yield	g/pot	2.28	9.38×10^{-4}	-7×10^{-8}	0.45	All
P	mg/pot	11.42	4.55×10^{-3}	-2.3×10^{-7}	0.38	All
K		110.17	8.10×10^{-2}	-3.77×10^{-6}	0.57	All
Ca		2.88	2.25×10^{-3}	-1.4×10^{-7}	0.81	All
Mg		2.33	1.91×10^{-3}	-1.2×10^{-7}	0.82	All
Cu	ug/pot	18.78	3.12×10^{-3}	------	0.40	All
Zn		124.37	3.76×10^{-2}	------	0.58	All
Fe		180.07	6.98×10^{-2}	-4.19×10^{-6}	0.48	All
Mn		87.29	1.80×10^{-1}	-9.41×10^{-6}	0.77	All

TABLE 16 - Continued

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
			Second Harvest			
Yield	g/pot	1.17	8.98×10^{-4}	-6×10^{-8}	0.48	All
N	mg/pot	11.48	1.90×10^{-2}	-1.23×10^{-6}	0.77	1
		33.30	2.43×10^{-2}	-1.28×10^{-6}	0.82	2
		98.64	3.34×10^{-2}	-2.51×10^{-6}	0.78	3
K		30.97	4.36×10^{-2}	-3.01×10^{-6}	0.50	All
Ca		0.80	1.65×10^{-3}	1×10^{-7}	0.64	All
Mg		0.71	1.45×10^{-3}	-9×10^{-8}	0.58	All
Zn	ug/pot	23.45	3.91×10^{-2}	-2.14×10^{-6}	0.49	All
Mn		18.44	1.09×10^{-1}	-7.43×10^{-6}	0.68	All

TABLE 16 - Continued

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
			Third Harvest			
Yield	g/pot	1.01	5.44×10^{-4}	-5×10^{-9}	0.41	All
P	mg/pot	1.49	1.93×10^{-3}	------	0.92	1
K		36.00	2.96×10^{-2}	-1.93×10^{-6}	0.58	All
Ca		0.95	1.25×10^{-3}	-7×10^{-9}	0.72	All
Mg		1.29	1.33×10^{-3}	-7×10^{-9}	0.70	All
Zn	ug/pot	69.09	1.49×10^{-2}	------	0.56	All
Fe		65.49	3.30×10^{-2}	-2.17×10^{-6}	0.39	All
Mn		15.95	1.29×10^{-1}	-9.44×10^{-6}	0.57	All

TABLE 16 - Continued

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
			Fourth Harvest			
Yield	g/pot	0.82	2.72×10^{-4}	------	0.77	1
		2.80	3.22×10^{-4}	------	0.48	2
		1.02	1.78×10^{-3}	-1.3×10^{-7}	0.88	3
N	mg/pot	56.59	1.02×10^{2}	------	0.64	3
P		2.73	------	2.6×10^{-7}	0.83	1
		21.34	2.14×10^{-3}	------	0.37	2
		12.22	1.78×10^{-2}	-1.4×10^{7}	0.84	3
K		7.12	2.12×10^{-2}	------	0.84	1
		49.25	3.70×10^{-2}	------	0.69	2
		31.88	5.45×10^{2}	------	0.81	3

TABLE 16 - Continued

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
			Fourth Harvest (Continued)			
Ca	mg/pot	1.32	7.93×10^{-4}	------	0.86	1
		5.05	1.01×10^{-3}	------	0.46	2
		0.86	3.30×10^{-3}	-1.5×10^{-7}	0.92	3
Mg		2.13	2.69×10^{-4}	------	0.39	1
		1.27	4.03×10^{-3}	-3×10^{-7}	0.74	3
Cu	ug/pot	7.43	------	1.1×10^{-7}	0.63	1
		4.66	9.42×10^{-3}	-5.7×10^{-7}	0.65	3
Zn		43.36	2.12×10^{-2}	------	0.42	All
Mn		102.92	8.85×10^{-2}	------	0.77	All

R^2 value of 0.31 for the linear and square terms of waterhyacinths added. Linear models were best suited to describe responses to applied waterhyacinths.

In evaluating the overall affect of waterhyacinths as a source of plant nutrients, total yields and nutrient uptake for the four harvests were analyzed (Table 17) The low available plant nutrient content of Laon fine sand was corroborated by the results obtained in the control treatment. Five- and six-fold increases in yield were obtained by the addition of fertilizer at levels 2 and 3. Addition of waterhyacinths at 2,231 ppm gave as good results as the application of fertilizers alone. Yields seemed to level off after 4,462 ppm of waterhyacinths without fertilizer. When both fertilizers and waterhyacinths were combined, yields were substantially increased. The extra supply of N-P-K provided for more vegetative growth and increased absorption of Ca, Mg, and micronutrients. Also a possible synergistic effect of fertilizer on decomposition of waterhyacinths increased supply of all plant nutrients, and reduced competition intensity between roots and microbes.

Nitrogen uptake was enhanced significantly by waterhyacinths. Uptake of N and P at low levels of applied waterhyacinths was not as good as those of fertilized pots. At 2,231 ppm, uptake of K, Ca, Mg, and micronutrients was as good as those observed at the high fertilizer rate. Manganese uptake was ten times greater. At other levels of applied waterhyacinths uptake of nutrients was higher than at the high fertilizer level. Since Ca, Mg, and micro-

TABLE 17

TOTAL YIELD AND NUTRIENT UPTAKE BY FOUR HARVESTS OF PEARL MILLET ON LEON FINE SAND

Treatment Wt**	F*	Yield*	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
		g/pot	------mg/pot------					------ug/pot------			
1	1	1.63	71	3	26	2	2	12	61	120	32
1	2	7.57	265	51	230	11	10	52	313	541	272
1	3	6.40	341	69	356	9	6	56	364	560	172
2	1	6.60	166	25	357	14	14	52	329	505	1079
2	2	11.07	328	77	525	19	21	73	446	766	986
2	3	17.30	546	150	767	26	30	97	704	1218	1467
3	1	12.00	264	47	560	24	19	63	514	696	1646
3	2	15.40	413	97	621	31	27	62	619	1052	1724
3	3	19.53	579	151	1009	36	34	133	952	1235	2104
4	1	12.97	295	79	754	31	24	83	713	669	2223
4	2	16.00	423	116	1054	39	34	85	1115	1226	2400
4	3	21.16	632	150	1332	48	42	162	1406	1621	2616
Overall mean**		12.60	364	65	650	24	22	79	645	669	1413
Std. dev		2.35	44	17	71	5	5	14	126	119	265

*Each value is an average of three observations.

**Waterhyacinth level (see Table 3).

*Fertilizer level (see Table 3).

**Each value is an average of thirty six observations.

nutrients were not applied with fertilizers, yield increases and higher nutrient uptakes were attributed to the contribution of waterhyacinths in increasing soil supply and availability of these plant nutrient elements. Overall, waterhyacinth amendments provided a balanced plant nutrient supply to pearl millet grown on Leon fine sand.

Regression coefficients for total yield and nutrient uptake by pearl millet versus applied waterhyacinths are given in Table 18. Optimum level of waterhyacinths was 7,500 ppm to obtain maximum yield For N uptake, optimum level was 7,500 ppm for all fertilizer levels. Linear responses to application of waterhyacinths were obtained for P uptake at fertilizer levels 1 and 2. Optimum level of waterhyacinths was at 6,000 ppm for maximum P uptake at the high level of fertilizer. For the other plant nutrients studied in this experiment, the optimum level of waterhyacinths to be applied varied between 5,000 to 10,000 ppm. Higher rates favored K, Ca, and Mg uptake.

Residual effects on chemical properties of Leon fine sand after amendment with waterhyacinths and four crops of pearl millet are given in Table 19. Addition of waterhyacinths increased soil C. Interaction between waterhyacinth and fertilizer was observed. Residual soil N was affected significantly by waterhyacinths applied. Residual soil P was influenced by both waterhyacinths and fertilizers with the latter playing a more significant role. The strongest residual effect of waterhyacinths was on K, Ca, and Mg contents of Leon fine sand. These elements were substan-

TABLE 18

REGRESSION COEFFICIENTS FOR TOTAL YIELD AND NUTRIENT UPTAKE VERSUS WATERHYACINTHS ADDED TO LEON FINE SAND

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
Yield	g/pot	5.99	3.17×10^{-3}	-2.1×10^{-7}	0.57	All
N	mg/pot	70.59	6.15×10^{-2}	-4.08×10^{-6}	0.96	1
		276.89	3.72×10^{-2}	-2.31×10^{-6}	0.56	2
		355.47	8.25×10^{-2}	-5.83×10^{-6}	0.87	3
P		5.80	8.44×10^{-3}	------	0.97	1
		57.35	7.31×10^{-3}	------	0.69	2
		75.51	3.13×10^{-2}	-2.6×10^{-5}	0.72	3
K		206.77	1.72×10^{-1}	-8.68×10^{-6}	0.72	All
Ca		7.02	6.78×10^{-3}	-3.5×10^{-7}	0.76	All
Mg		7.22	6.50×10^{-3}	-4.1×10^{-7}	0.64	All

TABLE 16 - Continued

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
Cu	ug/pot	14.56	1.62×10^{-2}	-9.6×10^{-7}	0.92	1
		52.57	1.02×10^{-2}	-7.4×10^{-7}	0.49	2
		56.63	2.14×10^{-2}	-1.07×10^{-6}	0.66	3
Zn		261.57	9.30×10^{-2}	------	0.65	All
Fe		130.36	1.76×10^{-1}	-1.05×10^{-5}	0.97	1
		525.54	1.43×10^{-1}	-7.11×10^{-6}	0.65	2
		622.07	2.21×10^{-1}	-1.25×10^{-5}	0.65	3
Mn		162.61	5.24×10^{-1}	-3.05×10^{-5}	0.90	All

TABLE 19

CHEMICAL PROPERTIES OF LEON FINE SAND AFTER AMENDMENT WITH WATERHYACINTHS AND FOUR CROPS OF PEARL MILLET

Treatment WH**	F+	Carbon*	N	P	K	Ca	Mg	Fe	Mn	Zn	NH_4^+	NO_3^-	Cl^-	Al Exch.	pH_{H_2O}	pH_{KCl}	ECEC	$CEC_{pH\ 7}$
		ppm															meq/100g	
1	1	11013	569	4	12	78	15	22	0.3	1	18	7	32	48	4.30	3.43	2.22	4.22
1	2	11249	556	10	13	74	12	19	0.4	1	15	3	29	43	4.38	3.50	2.08	3.92
1	3	11289	651	22	20	65	13	18	0.3	1	51	6	46	47	4.70	3.53	2.14	4.10
2	1	12237	563	5	15	131	27	21	1.6	2	8	5	40	43	4.20	3.57	2.37	4.14
2	2	11597	644	13	26	129	28	21	1.7	2	37	4	34	37	4.43	3.63	2.35	4.10
2	3	11592	804	17	24	131	25	20	1.7	2	12	3	29	38	4.50	3.63	2.34	3.81
3	1	11787	851	6	44	145	37	19	2.5	2	7	7	84	33	4.20	3.77	2.52	4.03
3	2	11253	657	18	45	183	40	20	2.9	2	10	8	88	35	4.30	3.80	2.47	4.08
3	3	13482	846	24	38	170	38	21	2.9	3	10	4	44	38	4.33	3.80	2.45	4.07
4	1	13114	844	11	161	223	58	17	4.3	2	6	11	201	22	4.40	4.23	2.75	4.34
4	2	12474	638	22	128	210	54	17	4.5	2	8	8	183	22	4.50	4.27	2.55	4.19
4	3	12522	678	33	113	229	56	19	4.7	3	7	6	123	23	4.47	4.20	2.71	4.40

TABLE 19 — Continued

Treatment WH**	P+	Carbon*	N	P	K	Ca	Mg	Fe	Mn	Zn	NH_4^+ N	NO_3^-	Cl^-	Al Exch	pH_{H_2O}	pH_{KCl}	ECEC	$CEC_{pH\ 7}$
		ppm															meq/100g	
Overall mean++		12049	627	15	53	147	34	19	2.3	2	14	6	74	35	4.39	3.78	2.41	4.11
Std dev.		589	45	5	36	46	11	3	0.9	1	5	2	15	4	0.08	0.06	0.15	0.23

*Each value is an average of three observations.

**Waterhyacinth level (see Table 3).

+Fertilizer level (see Table 3).

++Each value is an average of thirty six observations.

tially increased by application of waterhyacinths. Manganese and Zn were also increased. No significant affect of added waterhyacinths on residual soil Fe and Cu was observed.

Residual NH_4-N content of the soil was diminished by addition of waterhyacinths, but NO_3-N contents were increased. The energy supplied by carbonaceous materials and organic N probably contributed to stimulate heterotrophic nitrification (6, 40) at the low pH of Lean fine sand. The high Ca and Mg content may have provided a favorable microenvironment for autotrophic nitrifiers (8, 34). High Cl contents were observed at high levels of waterhyacinth application. However, exchangeable Al was reduced from 0.5 to 0.25 meq/100g by the addition of waterhyacinths.

Added waterhyacinths depressed soil pH, at low rates of application. At higher rates, soil pH was increased by addition of waterhyacinths. The lower soil pH effect was attributed to exchangeable Al, and hydrolysed NH_4 at low levels of waterhyacinth addition. As the level of waterhyacinths increased, ECEC, base saturation, and chelating capacity were increased, reducing exchangeable Al, and possibly H-ions in the soil solution (93, 94, 96).

Soil pH_{KCl} values and ECEC were increased by waterhyacinths additions. This effect combined with increased base saturation and reduced exchangeable Al were probably responsible for the increased yields and nutrient uptake by pearl millet. The effect of increased soil OM on exchange properties of Lean fine sand independent of pH was measured at pH 7.0. Cation exchange capacity was significantly

increased by waterhyacinth additions. The magnitude of the changes was not as large as that observed on ECEC measurements.

Regressions coefficients for residual soil chemical properties of Leon fine sand versus applied waterhyacinths are given in Table 20. Linear models best fitted the response of soil C to applied waterhyacinths at fertilizer levels 1 and 2. The slope at fertilizer level 2 was 70% of that observed without fertilizer. At fertilizer level 3, the intercept was the smallest and the response was quadratic. The maximum residual soil C was obtained when 6,000 ppm of waterhyacinths were applied at the high fertilizer rate. Residual soil N and P could not be adequately described by linear or curvilinear models. Residual K increased at all levels of applied waterhyacinths. Calcium, Mg, and Mn had positive linear responses to waterhyacinth additions. Exchangeable Al had a negative linear response to amendment with waterhyacinths. Ammonium-N showed interaction between fertilizer and waterhyacinths applied. A reduction in NH_4-N with increasing levels of waterhyacinths from 0 to 6,300 ppm was observed. Amendment beyond this point increased soil NH_4-N. Chloride content was best described by quadratic models, increasing with increasing rates of waterhyacinths at fertilizer levels 1 and 2. At fertilizer level 3, there was a decrease in Cl as waterhyacinths increased from 0 to 2,300 ppm. Amendment at higher rates increased Cl content of Leon fine sand.

TABLE 20

REGRESSION COEFFICIENTS FOR SOIL CHEMICAL CHARACTERISTICS VERSUS WATERHYACINTHS (WH) INCORPORATED INTO LEON FINE SAND

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
C	ppm	11236.93	2.05×10^{-1}	------	0.52	1
		11344.40	1.41×10^{-1}	------	0.40	2
		11033.60	6.83×10^{-1}	-5.68×10^{-5}	0.48	3
K		13.87	------	1.5×10^{-6}	0.70	All
Ca		84.89	1.60×10^{-2}	------	0.64	All
Mg		15.33	4.67×10^{-3}	------	0.73	All
Mn		0.51	4.61×10^{-4}	------	0.80	All
Exch. Al		46.00	-2.64×10^{-3}	------	0.84	All
NH_4-N		17.30	-4.04×10^{-3}	3.2×10^{-7}	0.82	1
		48.32	-1.54×10^{-2}	1.22×10^{-6}	0.83	3
		27.03	-6.93×10^{-3}	5.30×10^{-7}	0.41	All

TABLE 20 - Continued

Variable	Units	Intercept	WH	$(WH)^2$	R	Fertilizer Level
Cl	ppm	33.94	------	2.12×10^{-6}	0.99	1
		29.15	------	1.69×10^{-6}	0.99	2
		44.29	-9.9×10^{-3}	2.1×10^{-6}	0.91	3
pH_{H_2O}		4.36	-4.37×10^{-5}	1×10^{-9}	0.40	All
pH_{KCl}		3.49	4.99×10^{-5}	1×10^{-8}	0.96	All
ECEC	meq/100g	2.19	5.76×10^{-5}	----	0.52	All

Soil pH in water decreased with increasing rates of waterhyacinths from 0 to 2,200 ppm. Further addition of waterhyacinths increased soil pH. When measured in 1 N KCl, soil pH increased with increasing rates of waterhyacinth amendment. The ECEC of Leon fine sand increased linearly as the amount of waterhyacinths applied increased. This effect was attributed to increased OM, base saturation, and soil pH_{KCl} brought about by waterhyacinth amendments.

Field Experiment

Wachula fine sand and Leon fine sand are Spodosols with similar characteristics. The Wachula soil had more OM and N and slightly higher contents of extractable P, K, Ca, and Mg than Leon fine sand (Table 2). Soil pH and ECEC were essentially the same, but the CEC was higher in the Wachula fine sand than in the Leon soil. Data from Table 2 and the Soil Extension Office recommendations (44, 59, 60) indicated that use of the same management practices for growing pearl millet on Leon fine sand could be extrapolated to the Wachula fine sand.

Rainfall data collected adjacent to the experimental site are given in Table 21. Three months after liming, and two months after application of waterhyacinths, pearl millet seeded on the experimental area grew with an adequate supply of rain water. The favorable distribution of precipitation eliminated the need for irrigation.

Yields and nutrient uptake by two pearl millet harvests are given in Table 22. The effect of waterhyacinths was

TABLE 21

DAILY PRECIPITATION (MM) DURING THE GROWING SEASON AT THE BEEF RESEARCH UNIT (BRU) ADJACENT TO THE EXPERIMENTAL SITE, 1974

Day	April	May	June	July	August
1	--	---	---	---	---
2	--	---	---	10	8
3	--	---	14	---	25
4	--	27	---	--	---
5	--	15	---	---	---
6	--	38	---	---	56
7	--	---	23	---	---
8	--	---	5	33	---
9	--	---	---	8	---
10	--	---	18	---	---
11	--	13	18	8	---
12	18	30	6	---	9
13	--	---	---	---	---
14	--	--	---	---	---
15	--	17	84	---	---
16	--	4	---	---	15
17	--	41	---	---	---
18	--	---	---	14	19
19	--	34	---	---	---
20	--	---	---	---	---
21	--	---	---	24	---
22	--	---	---	9	9
23	13	---	---	---	---
24	--	---	38	---	3
25	--	---	23	---	8
26	--	---	17	14	---
27	--	---	---	5	---
28	--	---	---	8	---
29	--	---	---	6	---
30	--	---	---	---	---
31	--	---	---	---	---
Total	31	219	246	139	152

TABLE 22

YIELDS AND NUTRIENT UPTAKE BY TWO PEARL MILLET CROPS ON NACHULA FINE SAND

Treatment WH**	F+	Yield*	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
		----------kg/ha----------							------g/ha--------		
					First Harvest						
1	1	1189	14	6	48	4	3	5	40	207	94
1	2	1288	14	6	43	5	3	6	29	192	97
1	3	1225	13	6	43	5	3	5	30	156	96
2	1	1765	23	14	94	6	4	8	52	262	116
2	2	2674	37	19	122	10	6	17	82	374	227
2	3	1940	25	15	115	8	5	10	70	348	140
3	1	2229	31	18	125	6	6	9	79	281	192
3	2	3017	43	24	167	11	8	19	111	383	298
3	3	2733	33	20	170	12	7	13	108	421	260
Overall mean++		2007	26	14	105	8	5	10	67	292	169
Std. dev.		919	14	9	75	4	3	6	49	136	103
					Second Harvest						
1	1	3245	29	15	100	11	13	27	108	150	176
1	2	3030	29	14	72	12	15	25	104	122	216
1	3	3954	37	14	125	16	20	58	121	164	333
2	1	6330	61	26	176	22	27	71	240	253	374
2	2	3530	38	18	109	14	16	63	142	193	254
2	3	2935	34	13	53	11	11	20	117	147	178
3	1	6774	80	34	250	26	32	71	247	331	450
3	2	5845	68	33	233	22	22	105	215	295	309
3	3	5821	46	22	130	16	15	84	144	206	253
Overall mean++		4607	47	21	139	17	19	56	160	207	283
Std. dev.		2185	21	11	75	7	8	46	79	88	137

*Each value is an average of four observations.

**Waterhyacinth level (1 = 0, 2 = 15000, and 3 = 30000 kg/ha).

+Fertilizer level (1 = 0-0-0, 2 = 30-13-25, and 3 = 60-26-50 kg/ha N-P-K).

++Each value is an average of thirty six observations.

highly significant in increasing yields in the first harvest; however, no fertilizer effects were observed. Leaching, denitrification, and unfavorable conditions for nutrient absorption due to excessive rainfall may have been responsible for the lack of response of pearl millet to fertilizers (16, 23, 31, 61, 89, 92).

Nitrogen, P, Ca, Mg, and micronutrients recovered in the foliage of pearl millet were increased by waterhyacinths applied. These results agreed with those obtained in the greenhouse on Leon fine sand. Recovery of applied fertilizer was very poor to nonexistent when it was the only soil amendment besides lime. The organic nature of waterhyacinths proved more satisfactory in providing plant nutrients to pearl millet. This was attributed to increased supply and availability of plant nutrients derived from nutrient content of waterhyacinths and the larger volume exposed for root absorption. Second, it was observed that plots amended with waterhyacinths had a less compacted surface. Third, the increased microbial activity due to high energy carbonaceous compounds of waterhyacinth origin contributed to diminished leaching losses of plant nutrients. Similar effects were noted in a review by Black (5).

In the second and final harvest, yields were larger than in the first harvest. Application of additional N, plus reduction in rainfall in the last two months of the growing season were responsible for the improved yields. It was observed that on the limed Wechula soil, N application alone increased yields substantially. Waterhyacinth treat-

ments resulted in increased yields above control and fertilized plots. Fertilizer applications prior to the first harvest depressed yields and nutrient uptake on water-hyacinth treatments in the second harvest. Opposite effects were reported by Boyd (13) when using farmyard manures. There was a significant interaction between waterhyacinths and fertilizers in the Mg uptake by pearl millet in the second harvest. The high level of fertilizer reduced Mg uptake, and this was considered to be the cause of depressed yields when fertilizers were applied to waterhyacinth-amended plots. Magnesium concentrations in the tissue were adequate at harvest time, but the possibility of interference on Mg absorption by K and NH_4 at earlier stages of growth could not be ruled out (2, 19, 26, 46, 51, 58, 71).

Regression coefficients for yield and nutrient uptake by pearl millet versus applied waterhyacinths are given in Table 23. There was substantial variability in the field data and this accounted for the low R^2 values obtained. Yields increased linearly with the level of waterhyacinths applied. Increased supply of plant nutrients, and favorable conditions for nutrient absorption were responsible for the increased productivity of Wachula fine sand when amended with waterhyacinths. All nutrient uptake responses were linear, except for Fe uptake. The optimum level of water-hyacinths to be applied was 27,000 kg/ha.

In the second harvest, although waterhyacinths significantly increased yields and nutrient uptake, only Mg and Mn uptakes had R^2 values above 0.30.

TABLE 23

REGRESSION COEFFICIENTS FOR YIELD AND NUTRIENT UPTAKE BY PEARL MILLET VERSUS WATERHYACINTHS (WH) ADDED TO WACHULA FINE SAND

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
			First Harvest			
Yield	kg/ha	1293.88	4.75×10^{-2}	------	0.31	All
N		14.78	7.28×10^{-4}	------	0.31	All
P		7.04	4.78×10^{-4}	------	0.33	All
K		47.07	3.87×10^{-3}	------	0.34	All
Ca		4.88	1.89×10^{-4}	------	0.30	All
Mg		2.81	1.43×10^{-4}	------	0.31	All
Cu	g/ha	5.81	2.86×10^{-4}	------	0.24	All
Zn		33.61	2.23×10^{-3}	------	0.28	All

TABLE 23 - Continued

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
			First Harvest (Continued)			
Fe	g/ha	185.10	1.31×10^{-2}	-2.4×10^{-7}	0.28	All
Mn		91.82	5.15×10^{-3}	------	0.32	All
			Second Harvest			
Mg	kg/ha	14.16	6.35×10^{-4}	------	0.32	1
		14.78	------	1×10^{-8}	0.37	2
Mn	g/ha	195.99	9.15×10^{-3}	------	0.35	1

Total yield and nutrient uptake by two crops of pearl millet are given in Table 24. Yields were increased significantly by waterhyacinth additions to Wachula fine sand. Fertilizer applications depressed yield response by pearl millet when applied to plots amended with waterhyacinths. A similar response was observed for N uptake. Phosphorus, K, Ca, and Mg uptake was increased by waterhyacinth additions. Fertilizer application reduced uptake of these nutrients when applied on plots amended with waterhyacinths. Micronutrients were supplied by both fertilizer and waterhyacinths The uptake of micronutrients was reduced by fertilizer level 2, but increased at level 3. When waterhyacinths were added, micronutrient uptake was increased on all plots. Fertilizer at level 2 plus water hyacinths gave higher micronutrient uptake than waterhyacinths plus fertilizer level 3. Reduction of yields and nutrient uptake by pearl millet when fertilizer was applied on plots amended with waterhyacinths was explained in part as a Mg uptake problem This effect was puzzling, and probably merits further study. Total N uptake was also reduced by basal fertilizer applications.

Regression coefficients for total yield and nutrient uptake are given in Table 25. Yields increased linearly with the addition of waterhyacinths. Since some interaction was observed between waterhyacinths and fertilizer, equations for fertilizer levels 1 and 2 were calculated. The R^2 value for fertilizer level 3 was 0.17 and the equation was not reported. Nitrogen uptake was increased linearly by

TABLE 24

TOTAL YIELD AND NUTRIENT UPTAKE BY PEARL MILLET ON WACHULA FINE SAND

Treatment WH**	F+	Yield*	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
		----------kg/ha----------						-------g/ha-------			
1	1	4434	43	21	146	16	13	31	148	357	270
1	2	4318	42	20	114	17	16	30	133	314	313
1	3	5176	51	20	166	20	23	63	132	321	429
2	1	6063	64	40	270	26	31	76	262	314	490
2	2	6204	74	36	230	23	22	76	224	367	461
2	3	4674	36	26	166	16	16	30	167	495	316
3	1	11003	110	32	375	34	36	60	327	612	643
3	2	6632	111	56	420	34	30	124	327	679	607
3	3	6333	76	42	300	28	22	67	232	630	313
Overall mean**		6614	73	33	244	23	24	66	227	496	431
Std. dev.		2161	20	12	67	7	6	47	81	146	192

*Each value is an average of four observations

**Waterhyacinth level (see Table 22).

+Fertilizer level (see Table 22)

++Each value is an average of thirty six observations.

TABLE 25

REGRESSION COEFFICIENTS FOR TOTAL YIELD AND NUTRIENT UPTAKE BY PEARL MILLET VERSUS WATERHYACINTHS (WH) ADDED TO WACHULA FINE SAND

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
Yield	kg/ha	4532.41	1.39×10^{-1}	------	0.34	All
		4559.39	2.19×10^{-1}	------	0.51	1
		4189.63	1.51×10^{-1}	------	0.64	2
N		44.95	1.84×10^{-3}	------	0.53	All
		45.19	2.25×10^{-3}	------	0.63	1
		41.24	2.31×10^{-3}	------	0.75	2
		50.35	------	3×10^{-8}	0.32	3
P		20.06	1.01×10^{-3}	------	0.51	All
K		143.57	3.18×10^{-3}	1.4×10^{-7}	0.49	All

TABLE 25 - Continued

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
Ca	kg/ha	17.51	4.67×10^{-4}	------	0.40	All
Mg		16.89	7.46×10^{-4}	------	0.44	1
		18.05	1.23×10^{-4}	1×10^{-8}	0.54	2
Zn	g/ha	147.97	5.26×10^{-3}	------	0.38	All
Fe		343.71	1.03×10^{-2}	------	0.43	All

addition of waterhyacinths. At fertilizer level 3 the response became quadratic. All other nutrient uptakes, except K at all fertilizer levels, and Mg at fertilizer level 2, had linear responses to waterhyacinth additions.

The effects of added waterhyacinths on some chemical properties of Wachula fine sand are given in Table 26. Carbon, N, P, K, Ca, Mg, Zn, Mn, and Cl contents were increased in the soil by addition of waterhyacinths. Effective cation exchange capacity was increased significantly by addition of waterhyacinths. No significant effects were observed on Fe, Cu, NO_3, NH_4, and Al contents.

Regression coefficients for soil chemical properties of Wachula fine sand versus applied waterhyacinths are given in Table 27. Nitrogen, P, and K in the soil increased linearly with addition of waterhyacinths. Chlorides decreased as waterhyacinth additions increased from 0 to 2,760 ppm. However, further additions of waterhyacinths increased soil chlorides. Also ECEC of Wachula fine sand increased linearly in response to waterhyacinth applications.

TABLE 26

CHEMICAL PROPERTIES OF WACHULA FINE SAND AFTER AMENDMENT WITH WATERHYACINTHS AND ONE HARVEST OF PEARL MILLET

Treatment WH**	F+	C*	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn	Cl	NO_3	NH_4	Al Exch.	ECEC	pH_{H_2O}	pH_{KCl}
		-%-	ppm													meq/100g		
1	1	1.24	618	22	111	653	123	0.3	1.2	43	4	18	6	6	6	3.97	6.36	6.27
1	2	1.31	610	12	42	592	113	0.2	0.9	25	2	12	4	5	5	3.94	6.30	5.85
1	3	1.22	549	17	62	581	118	0.3	1.4	22	3	11	5	5	6	3.50	6.30	5.88
2	1	1.51	714	36	188	618	128	0.4	1.6	21	6	12	5	6	4	4.67	6.38	6.15
2	2	1.47	758	38	182	800	134	0.2	1.5	21	6	22	5	6	7	4.62	6.37	5.72
2	3	1.41	663	38	168	688	140	0.5	2.0	37	5	32	6	6	5	4.40	6.36	6.34
3	1	1.40	778	37	201	689	155	0.2	1.4	16	6	24	5	6	7	4.94	6.33	5.87
3	2	1.60	848	58	377	662	224	0.2	2.2	26	8	81	8	6	5	5.68	6.66	6.34
3	3	1.55	759	58	259	998	176	0.3	2.2	40	7	68	8	5	5	5.17	6.38	6.40

TABLE 26 - Continued

Treatment WH** F+	C*	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn	Cl	NO_3	NH_4	Al Exch.	ECEC	pH_{H_2O}	pH_{KCl}
	-%-	ppm												meq/100g			
Overall mean++	1.42	700	35	178	721	146	0.3	1.6	28	5	31	6	5	6	4.57	6.39	6.11
Std dev	0.24	139	20	110	231	58	0.2	0.7	17	3	29	2	1	3	0.84	0.21	0.18

*Each value is an average of four observations.

**Waterhyacinth level (see Table 22).

+Fertilizer level (see Table 22)

++Each value is an average of thirty six observations.

TABLE 27

REGRESSION COEFFICIENTS FOR SOIL CHEMICAL CHARACTERISTICS VERSUS WATERHYACINTHS (WH) INCORPORATED INTO NACHULA FINE SAND

Variable	Units	Intercept	WH	$(WH)^2$	R^2	Fertilizer Level
N	ppm	598.19	6.77×10^{-3}	------	0.32	All
P		17.94	1.14×10^{-3}	------	0.37	All
K		73.94	6.91×10^{-3}	------	0.41	All
Cl		13.58	-3.31×10^{-4}	6×10^{-8}	0.30	All
ECEC	meq/100g	3.84	4.87×10^{-5}	------	0.37	All

SUMMARY AND CONCLUSIONS

Lake Alice waterhyacinths had an average chemical composition comparable to the chemical composition of waterhyacinths from other Florida lakes and waterways. The use of waterhyacinths from Lake Alice as a soil amendment and a source of plant nutrients was studied in the greenhouse and in the field. Arredondo fine sand, Lakeland fine sand, and Leon fine sand were used in the greenhouse studies.

Dried and ground Lake Alice waterhyacinths at rates of 0, 2,231, 4,462, and 8,924 ppm and three levels of fertilizer (0, 45-25-50, and 90-50-100 ppm N-P-K) were randomly mixed with 5-kg portions of air dried soil. Each treatment was replicated three times and planted to pearl millet. After six weeks, the crop was harvested and the pots were seeded again. A total of four harvests was obtained from each treatment. After each harvest, the plants were dried and ground prior to chemical analyses for nutrient uptake. All data were analyzed statistically. After the last harvest, the soils were allowed to air dry, then they were sieved and analyzed for chemical properties.

Waterhyacinth amendments to Arredondo fine sand increased yields of pearl millet when added at levels higher than 4,000 ppm. Nutrient uptake was enhanced by application of waterhyacinths in those treatments where fertilizer

was added to the soil. After 12 months, applied waterhyacinths had residual effects in increasing C, K, Ca, Mg, and Mn contents in the soil. Significant increases in soil pH and ECEC were observed.

Amendment of Lakeland fine sand with waterhyacinths increased yields and nutrient uptake. Some water repellency problems were observed in the greenhouse at the higher rate of waterhyacinth application. The optimum level of waterhyacinths for maximum yields was at 6,000 to 8,000 ppm. Residual effects of applied waterhyacinths on chemical properties of Lakeland fine sand included increases in C, N, P, K, Ca, Mg, Mn, Zn, soil pH, ECEC, and CEC. Exchangeable Al was reduced.

In Leon fine sand, yield and N uptake increases were observed at all levels of waterhyacinth application. The optimum level was at 7,500 ppm for both. For other plant nutrients, optimum levels were between 8,000 and 10,000 ppm of waterhyacinths applied. The strongest effect on soil chemical properties by applied waterhyacinths was on the supply of K, Ca, and Mg of Leon fine sand. Some micronutrient contents were also increased. Waterhyacinths applied to Leon fine sand were as good as or better than fertilizers alone in increasing pearl millet yields and uptake of plant nutrients. Exchangeable Al was reduced and ECEC and soil pH_{KCl} increased linearly with increasing level of waterhyacinths.

For the field study, Lake Alice waterhyacinths at rates of 0, 15,000, and 30,000 kg/ha (dry weight basis) were

applied in a factorial design with three levels of basal fertilizer (0-0-0, 30-13-25, and 60-26-50 kg/ha N-P-K). The treatments were imposed on a completely randomized block design in a limed Wachula fine sand at the Beef Research Unit. The area was planted to pearl millet on June 4, 1974, and two harvests at six weeks intervals from planting were collected. After the first harvest on July 15, 1974, an application of 80 kg/ha N as NH_4NO_3 was made on all treatments. Waterhyacinths were better suppliers of nutrients than fertilizers. Pearl millet yields were higher on all waterhyacinth treatments than on fertilizer treatments. Fertilizers depressed yields and nutrient uptake when applied on plots amended with waterhyacinths. The optimum level for maximum yield of pearl millet was determined to be 27,000 kg/ha of dried waterhyacinths.

Application of waterhyacinths increased C, N, P, K, Ca, Mg, Zn, Mn, and Cl content of Wachula fine sand. Effective cation exchange capacity was also increased.

From greenhouse and field experiments it was found that waterhyacinths when used as amendments of acid sandy soils improved the soil environment for plant growth. Nutrient supply, base saturation, ECEC, OM, and soil pH were improved. In the greenhouse, waterhyacinths contributed significantly to the reduction of exchangeable Al.

The following conclusions can be drawn from results obtained in greenhouse and field experiments.

1. Crop response on soils amended with waterhyacinths increased as the soil pH_{H_2O} decreased from 6.1 for Arredondo fine sand to 4.0 for Leon fine sand.

2 Residual K, Ca, Mg, and micronutrient supply of soils studied was increased by waterhyacinth amendments. This increase in base saturation was matched by a decrease in exchangeable Al in Lakeland fine sand and Leon fine sand.

3. Waterhyacinth amendment of Lakeland fine sand and Leon fine sand was enough to supply plant nutrients without additional fertilizer. Extra N was needed and should be recommended when waterhyacinths are applied to Arredondo fine sand.

4. Soil amendment with waterhyacinths will increase C, pH, and ECEC.

5. Optimum rates of waterhyacinths were determined to be above 4,000 ppm for Arredondo fine sand without additional fertilizer applied. If extra fertilizer is supplied, the optimum levels increased to 7,000 to 8,000 ppm of waterhyacinths. For Lakeland fine sand and Leon fine sand optimum rate of waterhyacinths applied was 7,500 ppm.

6. Under field conditions, on Wachula fine sand, waterhyacinths added alone will be more than adequate as suppliers of plant nutrients and promoters of higher pearl millet yields. Yield responses were best described by linear models, although quadratic models would have been as adequate. Optimum level of waterhyacinths to be applied was 27,000 kg/ha for the conditions prevailing during this short term field experiment.

7. Wachula fine sand content of C and N, and extractable P, K, Ca, Mg, and Cl were increased by waterhyacinth applications. Effective cation exchange capacity was also increased as a result of increases in soil C brought about by amendment with waterhyacinths.

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BIOGRAPHICAL SKETCH

Jose V. Perra was born in San Marcos de Tarrazu, San Jose, Costa Rica, on April 2, 1946. He received his elementary and secondary education in Costa Rica. Upon graduation in 1962 he entered the Pan American Agricultural School in El Zamorano, Honduras. In December 1965, he received the degree of "Agronomo," and was awarded the Wilson Popenoe Scholarship to continue studies in the United States. In January 1966, he returned to Costa Rica, where he taught at an agricultural high school until August 1966. In September 1966, he entered the University of Florida as a junior, where he received his Bachelor of Science in Agriculture with honors in June 1968. He worked for the Department of Research and Development of American Oil Co. at Whiting, Indiana until October 1968. In January 1969, he returned to the University of Florida to obtain the degree of Master of Science in Agriculture. He graduated in June 1971. He worked as a lab technologist in the departments of Botany and Animal Science at the University of Florida until March 1972. After this date, the author rejoined the Soil Science Department working towards a Doctor of Philosophy degree under the direction of Dr. C. C. Hortenstine. Jose is married, with 2 children. He is a member of the American Society of Agronomy, the Soil Science

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I certify that I have read this study and that in my opinion it conforms to acceptable standard of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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